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THE GENESIS OF THE CHILEAN NITRATE DEPOSITS.[1]

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For over half a century the question of the origin of the Chilean nitrate deposits has been one of live interest. If the extent to which unanimity of opinion on the subject has been reached is a measure of the degree of success that has been attained in solving this problem, one is forced to the conclusion that no satisfactory explanation of the genesis of these remarkable deposits has yet been proposed. In reading over the extensive literature that deals with this question, one is impressed with the fact that, almost without exception, the writers have looked for some method by which unusually large quantities of nitrates might have been formed. With this accomplished, they have considered their task completed. All of the methods proposed are methods by means of which nitrates *can* be generated; and, if the conditions postulated by their sponsors *had existed*, most of them are adequate to have given rise to the extensive Chilean nitrate deposits. But, unfortunately, many of the conditions demanded by some of the explanations are obviously contrary to the facts; and, where this is not the case, the evidence is usually lacking to show whether the necessary conditions did or did not

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exist—in other words, the explanations are based on assumptions of greater or less probability. With such a state of affairs, one man's theory has been about as good as another's, and diversity of opinion still rules on the problem in question.

During a brief visit to the nitrate fields of the Province of Tarapacá last September, the pendulum of interest of the authors of this paper swung to the other extreme; and we were less interested in the *how of the formation* of the nitrate than we were in the manner of distribution of the nitrate deposits and the *how of their localization.* We soon had the feeling that the solution of the latter problem carried with it the solution of the former, or, at least, greatly minimized its importance. The particular purpose of this paper is to set forth our ideas in regard to the localization of the Chilean nitrates, and to discuss their bearing on the general problem of the genesis of these deposits. Before doing this we shall state briefly what theories have been advanced to explain them, and summarize some of the arguments for and against them.

Most of the theories that are or have been in vogue to account for the Chilean nitrate deposits may be grouped under four headings, according to the manner in which the nitrate is supposed to have been formed. These are:

1. The seaweed theories.
2. The guano theories.
3. The bacterial theories.
4. The electrical theories.

The seaweed theory was proposed in 1867 by Dr. C. N. Noellner. He believed that great quantities of seaweed collected along the portion of the west coast paralleled by the nitrate fields, due to the prevailing westerly winds, and that occasional hurricanes piled this up. An uplift of the land or a recession of the sea followed. The sea water that remained behind evaporated and furnished the sodium chloride, while the nitrates resulted from the slow oxidation of the seaweed. The great argument in support of this theory was the presence of iodine in the nitrates. Until iodine was extracted from the mother liquors of the nitrate oficinas, seaweed was the only known source of the element.

That the presence of iodine requires no special explanation is obvious form the fact that silver iodide occurs associated with silver chloride in the horn silver ores found so abundantly in the zone of oxidation of silver deposits in all arid regions. This theory has so few facts to support it that it has had few adherents.

There are really two groups of guano theories. In 1860, C. G. Hillinger advanced the theory that the nitrates are due to extensive deposits of guano that covered the banks of a large saline sea. The saline waters flooded the guano and reacted with the nitrogen to finally form sodium nitrate. Very similar is the theory proposed in 1894 by A. Gautier. He derives the nitrates from bird guano in the form of calcium nitrate. This was then liquefied little by little by the night dews, and thus brought into contact with the salt of the "salars," basin-like depressions in the pampa characterized by an abundance of sodium chloride, where it was converted into sodium nitrate. The most detailed presentation of this theory was made in 1910 by R. A. F. Penrose, Jr. He believes the nitrate region was once part of the ocean bottom, and finally an interior basin occupied by salt lakes. Guano beds deposited about the borders of these lakes furnished nitrates that were carried down into their waters.

The other guano theory is that of C. Ochsenius, proposed in 1887. One of the main objections to the guano theory had been that the "caliche" is practically free of phosphates, whereas guano is rich in phosphates. Penrose, in reply to this objection, suggests that the phosphate may actually exist on the pampa, which is still but little explored and known outside of the areas of workable nitrate. To avoid this objection entirely, Ochsenius had his guano blown in from the guano deposits on the islands of the Pacific by the prevailing westerly winds. His argument is that the winds would carry in the lighter nitrogenous portion of the guano, and leave behind the heavier phosphatic portions. In 1903, Ochsenius receded from his original theory to the extent of regarding the wind-blown guano merely as the inciter of the nitrification process, and that the main source of the nitrates was the oxidation of the nitrogen of the air.

The exponents of the guano theories all point to the forma-

tion of calcium nitrate from bat guano in caves, and the widespread occurrence of such cave nitrates in dry caverns, as the basis of their ideas. In 1900, however, W. H. Hess showed that only a small part of the cave nitrate originates in this way, but that it is due for the most part to the evaporation in dry caves of descending waters that have leached out the nitrate content of the surface soil.

The way for the bacterial theory was paved in 1862, when Pasteur suggested that the oxidation of the nitrogen compounds in the soil is accomplished by living organisms. Warrington, in 1877, described in a series of articles the favorable and unfavorable conditions under which this action proceeds. In 1885 A. Müntz explained the formation of the Chilean nitrates as the result of the action of these nitrifying organisms on organic matter. The presence of iodine, and the fact that sodium and not calcium nitrate occurred, seemed to necessitate to him the presence of sea water or salt marshes during the process of nitrification. The best presentation of this theory is that by Dr. William Newton, in 1896. He ascribes the genesis of the nitrate to the action of the nitrifying organisms on ancient vegetable matter in the soil of the region. The nitrates thus formed, he says, have been collected by the drainage waters of the entire region, and gathered and evaporated at the site of the present nitrate deposits, which is the point where these waters are stopped by the coast line of hills. As thus developed, this is one of the most plausible theories that have been advanced. It was subscribed to by A. Plagemann in 1897, and by G. E. Bailey in his report on the California nitrate deposits in 1902, and was regarded more favorably than any other by F. W. Clark, in 1908, in his "Data of Geochemistry."

The electrical theory has been repeatedly referred to in the literature, but no one in particular seems to stand out as its champion. It was advocated in 1903 by Dr. Semper, and in the following year, by Semper and Michels in their paper on the nitrate deposits. Many of those putting forth other theories admit this as a subordinate contributing factor. According to the more prevalent form of this theory, the nitrates are formed by the oxidation of the nitrogen of the air through the electro-

static tension that is such a marked accompaniment of the frequent coast fogs, or "camanchacas," that roll in over the nitrate pampa at night. The principal evidence of the existence of this "static" condition seems to be the disturbance of telephone service between Iquique and the nitrate oficinas when the pampa is enveloped in these fogs. But may not this disturbance be due to another cause? During the afternoon wind storms on the pampa, the telephone poles, insulators and wires become covered with the saline pampa dust. When the fog comes on, this dust absorbs moisture, becomes an excellent conductor, and grounds the circuit. This is happening at every pole on the line. Under these circumstances, static atmospheric conditions need not be invoked to explain poor telephone service.

An atmospheric source of nitrates that has received less attention, is that formed during electrical storms in the Andes. This has certainly been at least a contributing factor to the nitrate supply of the region.

This review of the theories to explain the formation of the Chilean nitrate deposits has been necessarily extremely brief, yet it is hoped that it has been sufficiently full to bring out the fact that, however plausible they may be, evidence to establish the proof of any one of them is far from sufficient.

Briefly put, our theory is that the nitrate deposits have resulted from the accumulation, by means of evaporation, of the minute nitrate content of the underground waters of the region. In other words, they represent a sort of efflorescence of soluble salts out of the ground-water. This accumulation has been made possible through the remarkable relations of ground-water and climate existing in the region of the nitrate deposits, conditions which will now be described.

It is a well-known fact that the nitrate pampas belong to the most arid areas on the face of the earth. In some parts rain almost never falls, and everywhere intervals between rainfalls are measured in terms of years. The prevailing westerly winds coming in from the Pacific drop most of their moisture in crossing the zone of the cold Humboldt current that lies just off this coast. As they are warmed up again on reaching the coast and

blow across the pampa, they are highly deficient in moisture and have a tremendous power of evaporation. Likewise the occasional winds that come down from the Andes have lost nearly all their moisture in the cold high summits of that range; and, as they reach the pampa, absorb with great avidity any moisture they come in contact with. A hot tropical sun shining from a cloudless sky is an important adjunct in intensifying this aridity. It is true that as the temperature falls at night, heavy fogs from the sea, known as the "camanchacas," frequently roll in over the coast range and cover the pampa; but, as soon as the rays of the sun strike this fog, it vanishes as if by magic. The pampa is consequently a dust-covered surface on which no vegetation is seen, overlain by an atmosphere whose powers of evaporation are at a maximum.

In a country of such aridity and at an elevation of several thousand feet, one would normally expect to find the depth of ground-water to be measured in hundreds of feet. One of the remarkable features of this nitrate region is the shallow depth at which ground-water is encountered, the depth being measured in tens of feet. For instance, over the nitrate-bearing ground of the Oficina Paposas at La Noria, the depth of ground-water is only twenty to twenty-five feet; and in a "salar" at Lagunas, it actually stands in open ditches at a depth of little more than three feet. The pampa has been built up with loose porous detrital material washed down mainly from the slopes of the Andes on the east. Through such material, capillarity is very effectively feeding the shallow ground-water in enormous quantity to the atmosphere through evaporation. Whatever soluble salts this ground-water is carrying are left behind to accumulate in the soil between the surface and the ground-water level.

However great this loss of ground-water may be, the supply is incessant and ample. There is a constant flow of ground-water from the regions of more abundant precipitation in the higher slopes of the Andes on the east, westward beneath the pampa, toward the sea. The pampa has a gentle westward slope to the foot of the coast range, where the presence of these mountains causes an abrupt rise in the topography. Since the surface of

ground-water follows in its general outlines the overlying topography but is less accentuated than the latter, the ground-water level should lie nearest the surface on this western edge of the pampa; and consequently here should take place the maximum evaporation, and for that reason, the maximum accumulation of soluble salts.

Now, let us consider a few facts in regard to the manner of occurrence of the nitrate deposits. They are by no means uniformly distributed over the whole pampa, but are practically limited to the western edge. Even along this western edge the deposits are not continuous, but occupy restricted areas, and their topographic position is not always the same. In the southern and central part of the Tarapacá field, the nitrate areas tend to occur around the "salars," which are depressions in the pampa characterized by an abundance of salt and absence of nitrate. The richest nitrate ground is frequently that immediately contiguous to the "salars," and the nitrate tends to decrease in quantity with increasing distance and elevation above the "salar." There are often small knolls within a "salar," and these also carry nitrate above its level. In the northern part of this field the nitrate tends to occur on the lower slopes of the hills that rise abruptly out of the pampa, and not on the pampa itself. The nitrate is encountered where the rise of the hills begins and diminishes in quantity with increasing elevation.

The fact that the nitrate occurs around and not in the "salars" is easily understood, in view of the deliquescent nature of this substance. Suppose that salt and nitrate had accumulated in these depressions. When a rain did come, or when the pampa was deluged, as it occasionally is, by torrents bursting down from the Andes, these would be the places for the waters to collect before they had been completely dissipated through seeping into the soil and by evaporation. They would be the wettest places and the last places to remain wet. Whatever nitrate existed there would be taken into solution, and it would at once begin to effloresce out of the boundaries of the "salar," as, for instance, sal ammoniac crawls out of its solution into the La Clanche cell, and accumulates in the dry ground surrounding it. This process repeated at inter-

vals would keep the "salar" free of nitrate, and leave the accumulation of salt behind. The manner of occurrence in the north pampa is such as would take place if this pampa were covered by a relatively impervious stratum, such as a layer of fine silt, that would reduce evaporation of ground-water to a minimum. The belt of maximum evaporation would then be in the more porous ground lying just above the pampa level where ground-water would be nearer the surface than farther up on these slopes. Nitrate ought to be most abundant at the foot of such slopes and decrease in quantity upward, which is actually the case.

Coming back to the conditions existing at the upper surface of the ground-water, we have it subjected to a constant evaporation with a rapidity dependent on its nearness to the surface and the porosity of the overlying soil. Though the amount of this evaporation, on account of the aridity of the climate, is great over the whole extent of the pampa, in general it is not sufficiently so to admit of the accumulation of the soluble salts; or, if they do collect, the ground is washed out frequently enough in the eastern part of the pampa, by descending rain waters and the waters of the mountain torrents that flood it, to carry the salts back into the general ground-water circulation. This evaporation of the upper layers of ground-water leads to a concentration of the soluble materials that they carry; but, counteracting this tendency to concentration, is the slow seaward movement of these waters and the downward diffusion from the concentrated layers to the lower more dilute layers. Under most conditions, these dissipating influences are sufficiently strong to prevent the point of saturation being reached in the upper layers. As the western edge of the pampa is reached and the ground-water comes nearest the surface, the amount of evaporation increases rapidly; and where a particularly porous area exists, it reaches a maximum. To compensate this loss by evaporation, there is a constant influx of water which more than counterbalances the tendency of the westward flow and downward diffusion to equalize the concentration. Finally the concentration reaches such a degree at these places that an efflorescent salt like sodium nitrate will begin to "crawl out of the solution," as it were, and be deposited in the overlying

soil. This process, long continued, will lead to accumulations of large deposits of sodium nitrate, irrespective of how minute a quantity the original ground-water carries. At these places will accumulate a large part of the nitrate collected by the ground-waters from the entire surrounding region. Sodium chloride having a weaker tendency to effloresce, will not be accumulated as readily, and hence will exist in a smaller relative quantity in the accumulated salts than in the original waters.

To sum up, all underground waters carry some nitrate, however small the quantity. As Hess has demonstrated in the case of nitrate earths in dry caves, wherever these waters tend to converge to a point of evaporation, the nitrate will accumulate. The abnormally high rate of evaporation existing at the most favorable points in the nitrate pampas furnishes just such points of convergence and accumulation for the nitrate content of the waters flowing from the Andes to the sea underneath the pampas. These most favorable points, we have shown to be the areas on the western edge of the pampa where the ground-water comes nearest the surface and where the overlying soil is most porous. The abnormal conditions of extreme aridity and shallow ground-water suffice to explain, in large measure at least, the unusual accumulations of nitrates that have taken place.

If there is or has been an unusual activity in the generation of nitrates in this region, as the authors of the older theories have felt it necessary to assume, it merely means that it has taken less time to accumulate the present deposits than if there had been no such unusual activity. Though the advocates of each of these theories have pointed out the inadequacy of the rest as sources of nitrates, yet they have in most instances adduced sufficient evidence to show that their own process was in all probability a factor. In fact, there is every reason to believe that the quantity of nitrates carried into the ground-waters of this region was and is somewhat more than the average. Thus the finding of local patches of bird guano in the costra, in which frequently feathers are preserved and even whole skeletons of birds, shows that there has been a constant addition of nitrogenous animal matter through this source. There is, however, no evidence to warrant an as-

sumption that this ever took place on a sufficiently large scale to account for all of the nitrate. It would be useless to deny that the prevailing westerly winds have blown guano dust, from the Pacific islands or the cliffs along the coast that are inhabited by multitudes of sea birds, that had settled on the pampa; but one finds it difficult to believe that this could have taken place on the scale demanded by the enormous quantities of nitrates, if this were their principal source, and Ochsenius, the promulgator of the theory, subsequently receded from this position himself. Whether the nitrifying bacteria ever had a sufficiently favorable environment to generate the necessary amount of nitric acid is problematical. Certainly, at the present time, the environment is not particularly favorable; and certain it is, the more favorable the environment for their generation in this way, the less favorable the conditions for the accumulation of the nitrates formed. Hence one hesitates to expect too much from this source. In the light of recent achievements of the Germans in manufacturing nitrates from the air, one is more inclined to regard this source with favor. But whether the "camanchaca" has played an important role in the generation of nitrates from the air through electrostatic tension is still doubtful in view of the fact that it seems likely that the electrical activity accompanying the "camanchaca" has been greatly exaggerated through a misinterpretation of the phenomena. A more likely field for the generation of nitrates in this way would seem to be the Andes themselves, where electrical storms do hold sway.

But these are after all merely the processes by which nature is generating nitrates all over the surface of the earth. The only feature in which this region might be unique in the generation of nitrates is that apparently more of these processes have been active here than is generally the case in other places. There is no evidence to show that any one of these possible sources would be adequate to account for all of the nitrate, and we believe that all combined would be inadequate, if it were not for the all important remarkable conditions of climate, underground waters, and geologic structure existing in the region. The essential factors in an explanation of the genesis of these deposits are the last

mentioned, the former are of importance primarily in determining the rate of accumulation, and hence the amount existing at any given time. We believe that former attempts to satisfactorily explain these deposits have failed, because undue emphasis has been laid on the mode of generation of the nitrates, whereas the fundamental explanation lies in the conditions that have made possible their accumulation.

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THE OXIDATION OF MANGANESE SOLUTIONS IN PRESENCE OF THE AIR.

VICTOR LENHER.

It is well known that manganous solutions when neutralized undergo hydrolysis, and that when such solutions are allowed to stand in contact with the air, oxidation takes place with the precipitation of hydrated manganese dioxide. In the presence of the common alkalis, manganous salts yield manganous hydroxide, which when exposed to the air undergoes oxidation with the formation of hydrated manganese dioxide.

The deposition of pyrolusite, the most plentiful of the manganese ores, in nature is doubtless the result of a series of reactions of neutralization and oxidation. Manganese is presumably transported in nature as bicarbonate, sulphate, or chloride. When a manganese-bearing solution comes in contact with such a substance as calcium carbonate which is so widely distributed in nature, the manganese salt is neutralized, hydrolysis takes place; the action of the oxygen of the air enters, and manganese dioxide is precipitated, the calcium carbonate serving to neutralize the free acid which is liberated in the reaction.

In studying the reactions incident to the deposition of manganese dioxide by the neutralization of manganese salts and the subsequent oxidation by means of air, a series of observations has been made by the writer which at first seemed to be examples of certain principles of positive and negative catalysis.

A large number of glass tubes were cleansed with the utmost care, and in each tube was placed a one per cent. solution of pure manganous chloride, a piece of Iceland spar, and a piece of metal, mineral or metallic compound. The solution and solids filled about one fourth of the tube; the remainder of the space was occupied by air. These tubes were then sealed in the blast flame

and allowed to stand for a long time in order to allow the slow oxidation by the air to take place. Very striking differences in behavior are exhibited by the various metals under these conditions. Certain of the metals cause the production of manganese dioxide to be accelerated, while others cause its formation to be retarded, or in some cases to be actually inhibited. Lead and bismuth accelerate the deposition of manganese dioxide from a manganese chloride solution when calcite is present as a neutralizing agent.

In blank experiments made with only manganese chloride solution and Iceland spar, the first noticeable separation of manganese dioxide appears only after standing for several weeks. With metallic lead present in the solution a greater amount of the dioxide separates out over night than in several weeks in the blank experiments. Certain other metals, such as tin, arsenic, and antimony, prevent this oxidation of the manganese with formation of manganese dioxide. In fact they inhibit it entirely.

Such metals as mercury, copper, zinc, nickel, cobalt, cadmium, silver, gold, as well as mercuric sulphide, millerite, pyrite, chalcopyrite, and zinc blende, are without any effect in this reaction, the tubes at the end of a number of months of action appearing to be identical with those in which only the manganese solution and Iceland spar were present.

The acceleration of the oxidation of the manganese by the oxidation with air in presence of lead is not necessarily dependent on the presence of the metal itself, since lead sulphide, carbonate or sulphate also accelerate this reaction; nor is the reaction dependent on the use of the chloride of manganese, inasmuch as the sulphate or acetate of manganese also works equally well.

The retardation of this oxidation in the presence of metallic antimony, arsenic or tin, is readily explained by the reducing action of their salts toward manganese dioxide. The alkaline stannites, arsenites and antimonites reduce manganese dioxide; consequently in their presence it cannot be produced. The lack of reaction cannot, therefore, be regarded in the light of a negative catalysis.

Further, the presence of a higher oxide or salt of a higher oxide of these elements is without any appreciable effect on the reaction. Thus, in the presence of an arsenate, stannic oxide, or antimonic oxide the oxidation and subsequent deposition of manganese dioxide proceeds in the same way as though these substances were absent.

The presence of a reducing substance when a neutralized solution of manganese is exposed to the air, impedes the oxidation and formation of manganese dioxide, or actually prevents it. Such substances which in general are not reducing in character, as the common metals mercury, copper, cadmium, zinc, cobalt, silver, and the minerals cinnabar, millerite, pyrite, chalcopyrite, sphalerite, magnetite, hematite, corundum, bauxite and ilmenite, are without apparent influence on this oxidation.

Lead and lead compounds accelerate this oxidation greatly; bismuth and bismuth compounds also accelerate the oxidation, but to a lesser degree than lead.

From our numerous experiments along these lines, it is apparent that in the laboratory, lead and lead compounds act as a great accelerator in the production of manganese dioxide when we attempt to imitate the agencies which apparently go on in nature in the formation of manganese deposits.

Thus far however no regular association of lead with the oxidized manganese minerals has been noted in the field, so far as the writer is aware.

SERICITE A LOW TEMPERATURE HYDROTHERMAL MINERAL.

AUSTIN F. ROGERS.

Of the various non-metallic minerals associated with ores, sericite is one of the most abundant and important. It is especially prominent in the wall rocks adjoining veins as emphasized by Lindgren in his classic paper, "Metasomatic Processes in Fissure Veins."[1]

While it is the general belief that sericite is of hydrothermal origin few attempts have been made to define its temperature range or to determine its age with reference to the other gangue-minerals and ore-minerals. Apparently the necessary data have often been lacking. The general impression is that sericitization is contemporaneous with ore-deposition.[2] In most of the cases where the relative age of sericite has been determined it has been assigned to an early stage of mineralization (Butler, Kirk, Irving and Bancroft, Spurr, and Stewart), while, on the other hand, the writer has found that it belongs to a late stage of mineralization, and that it is almost invariably formed after the sulphides.

That sericite is a comparatively low-temperature mineral formed at, or toward, the end of the hydrothermal period is the author's thesis. In addition to original descriptions of sericite, this paper also includes a review of opinions concerning the occurrence and origin of sericite.

The writer is indebted to his colleague, Professor C. F. Tolman, jr., for criticism of this article.

For any mineral there are two general classes of facts to be

[1] *Trans. Amer. Inst. Min. Eng.*, Vol. 30, pp. 578–692 (1900). Reprinted in Posepny volume, "Genesis of Ore Deposits," pp. 498–612.

[2] Lindgren, for example, says (ECON. GEOL., Vol. 2, p. 203, 1907): "Neither is it apparent why these ascending solutions should not have deposited chalcopyrite and pyrite in the porphyry with simultaneous sericitization, such as generally takes place under influence of hot waters."

established: (1) The properties of the mineral (crystallographic, physical, and chemical), and (2) the occurrence, association, and origin of the mineral (paragenesis in the broad sense[3]), or what Clarke[4] has called the natural history of a mineral. Before the paragenesis or natural history of sericite is discussed, its properties will be briefly considered.

PROPERTIES OF SERICITE.

Sericite is the name given by List[5] to a micaceous mineral occurring in schists in Taunus. Laspeyres[6] proved that sericite is essentially identical with muscovite in chemical composition. Spurr[7] uses muscovite and sericite interchangeably. There is a possibility that fluorine is present in muscovite and absent in sericite, but very few complete analyses of sericite are available, and the fluorine determination is an especially difficult one.

Whether sericite is chemically identical with muscovite or not, another factor must be considered. An important part of mineralogical work in recent years has consisted in the reduction of varieties and synonyms. There is, however, a counter movement in the establishment of polymorphous modifications of the various naturally occurring chemical compounds. The phenomenon of polymorphism seems to be a general one,[8] but comparatively few polymorphous minerals are known or recognized. Some of the varietal names of minerals must be elevated to the rank of mineral species, for example, adularia. It is possible that sericite is dimorphous with muscovite. There are differences in crystal habit (the crystals are thin tabular, and are apt to occur in elongated forms) and in certain optical properties such as the optic axial angle ($2V = 20°$). The differences in occurrence which are correlated with temperature are even more suggestive. At any rate, sericite is a useful term for the low temperature mineral with the approximate chemical composition of muscovite.

[3] Rogers, ECON. GEOL., Vol. 7, p. 638 (1912).
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[7] Professional Paper 42, U. S. Geol. Surv., p. 232 (1905).
[8] Arzruni, Physikalische Chemie der Krystalle, p. 22 (1893).

Sericite generally occurs as minute scales, fibers, or shreds, usually not distinctly visible to the naked eye. Distinct individual crystals are very rare, and sericite rarely develops except as a metasomatic mineral. An interesting exception has been studied by the writer. Euhedral crystals of sericite were found in a cavity in a specimen of altered monzonite collected at Bingham, Utah, by Mr. J. J. Beeson. These crystals are thin tabular pseudo-hexagonal with extinction parallel to one edge like muscovite.

Sericite has been found as a replacement of various silicates, especially the feldspars, and more particularly plagioclase. It is also a common replacement of quartz and occasionally of calcite. In the present paper the replacement of sulphides (pyrite, chalcopyrite, bornite, chalcocite, covellite, galena, and sphalerite) by sericite is described.

Among the characteristic optical properties of sericite are the variation in the relief in polarized light, the strong double refraction, the elongation parallel to slower ray, and the parallel extinction. The change of relief when rotated on the stage of the microscope is especially characteristic. Sericite, like muscovite, has moderate relief (in Canada balsam) when the elongation of the section is parallel to the vibration plane of the lower nicol and low relief when the elongation is perpendicular to the same. Fragments may be tested in clove oil ($n = \pm 1.535$) when the change of relief is as given above. With bromoform ($n = \pm 1.597$) the change of relief is even more marked, but in this case the sericite has moderate relief when the elongation is perpendicular to the vibration plane of the lower nicol and low relief when the elongation is parallel to the same. These tests follow from the optical constants of sericite which may be taken the same as those of muscovite:

$$[n_\gamma = 1.597,\ n_\beta = 1.593,\ n_\alpha = 1.560;\quad n_\gamma - n_\alpha = .037;\quad c = \alpha.][9]$$

When sericite occurs within feldspars and other crystals the interference colors are best observed by revolving the stage until the feldspar or other crystal host is in extinction position.

[9] I use α, β, and γ for the axes of the optic ellipsoid, and n , n and n for the corresponding indices of refraction.

Among minerals likely to be mistaken for sericite are kaolinite, chlorite, and calcite. Minute shreds of organic matter from Canada balsam may also at times resemble sericite. Kaolinite and chlorite have very weak double refraction and no variation in relief when rotated. Kaolinite is almost opaque white by reflected light, while sericite is transparent, but the opacity of kaolinite is probably due to the extremely small size of the individual crystals. Sericite is fusible, while kaolinite, if pure, is infusible. The water content of sericite is about 4.5 per cent., while that of kaolinite is about 14 per cent. In polished sections of the copper ores from the Engels mine, Plumas county, California, a choritic mineral occurs in lath-shaped sections so exactly like the sericite in other specimens, that thin sections are necessary to distinguish the sericite from chlorite.

THE OCCURRENCE OF SERICITE.

Sericite has been recognized in nearly all the types of ore-deposits which seem to have any connection with igneous rocks, ranging from magmatic sulphide deposits and pegmatites through the deep high-temperature veins and deposits formed at intermediate depths to deposits formed near the surface. Its occurrence in these various classes of ore-deposits will now be discussed, beginning with the magmatic ores.

SERICITE ASSOCIATED WITH MAGMATIC ORES, ENGELS MINE, PLUMAS COUNTY, CALIFORNIA.

The writer first observed sericite as a replacement of sulphides in specimens of magmatic copper ores from the Engels mine in Plumas county, California.[10] The sericite occurs as definite, sharp-cut crystals which appear as lath-shaped sections. (See Figs. 1, 2, 3, 4, 9, 10, and 11.) The sericite replaces chalcopyrite, bornite, and chalcocite. Chalcocite usually appears in close association with sericite, and for this reason the writer decided (in the paper referred to) that chalcocitization was accompanied by sericitization. The study of additional specimens

[10] Econ. Geol., Vol. 9, pp. 359–391 (1914).

EXPLANATION OF PLATE III.

Specimens from No. 5 tunnel, Engel's mine, Plumas County, California. (*s*, sericite; *b*, bornite; *cc'*, hypogene chalcocite; *cc*^{2}, supergene chalcocite; *f*, feldspar; *t*, tourmaline.)

FIG. 1. (×20 diameters.) Thin section. Sericite cutting bornite and chalcocite.

FIG. 2. (×57.) Polished section, showing bornite and chalcocite with sericite.

FIG. 3. (×700.) Polished section. Sericite cutting bornite-chalcocite area.

FIG. 4. (×157.) Polished section. Sericite cutting bornite and bordered by chalcocite.

FIG. 1.

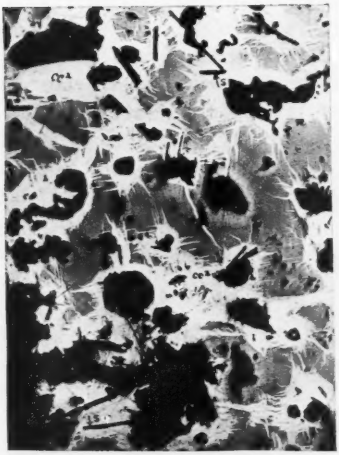


FIG. 2.

FIG. 3.

FIG. 4.

recently received from the Engels mine caused a modification of this view. It may be stated, however, that the evidence in favor of "upward enrichment" of the bornite by chalcocite is even stronger than before. Further study of the Engels ores shows conclusively that there are two periods of chalcocite enrichment instead of one. The first generation of chalcocite is hypogene chalcocite formed before sericite (and chlorite), while the second generation of chalcocite is supergene chalcocite formed after the sericite (and chalcocite). In both cases chalcocitization is independent of sericitization.

There are several types of the chalcocite-enriched ores, all of which were formed from magmatic chalcopyrite or bornite, principally the latter.

Figs. 1–4 are microphotographs of specimens from No. 5 tunnel. Fig. 1 represents a thin section showing sharp lath-shaped sericite crystals cutting the opaque sulphides which are bornite and chalcocite. The light-colored mineral is largely plagioclase, in part sericitized. Tourmaline, chlorite, epidote, and quartz are also present.

Proof of two generations of chalcocite is furnished by Figs. 3 and 4. In Fig. 3 sericite cuts the irregular chalcocite-bornite area, showing it to be later, while in Fig. 4 the sericite crystals are bordered by chalcocite. In this case the bornite-sericite contacts have simply furnished capillary channels for the introduction of chalcocite-bearing solutions. In this specimen we have clear evidence of two generations of chalcocite, one formed before the sericite, the other after the sericite.

Figs. 6–8 are microphotographs of polished sections of another specimen from No. 5 tunnel of the Engels mine (No. 18 of Fig. 91 of the paper cited). This is a type quite different from that just described. Bornite has altered to covellite and bluish chalcocite, usually along crystallographic directions. Some sections show this type of alteration almost entirely free from sericite, which indicates that the chalcocite and covellite enrichment is independent of sericitization. Sericite occurs in these specimens, but the lath-shaped crystals are for the most part a colorless mineral of weak double refraction and negative elongation which is

EXPLANATION OF PLATE IV.

Polished sections of specimens from Engel's mine, Plumas County, California. (*ch*, chlorite; *b*, bornite; *cc'* hypogene chalcocite; cc^2, supergene chalcocite; *cv*, covellite; *cp*, chalcopyrite.)

FIG. 5. (×125.) Chlorite cutting bornite and bordered by supergene chalcocite.

FIG. 6. (×125.) Chlorite cutting bornite, chalcocite and covellite.

FIG. 7. (×375.) Chlorite replacing covellite and bornite.

FIG. 8. (×375.) Chlorite replacing bornite and hypogene chalcocite and bordered by narrow rims of supergene chalcocite.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

referred to the chlorite group (perhaps leuchtenbergite). What is true of the chlorite is also true of sericite, as the thin section proves that sericite is later than the chlorite. If the chlorite is later than the covellite and chalcocite the sericite is also. Fig. 6 illustrates a speck of sulphide surrounded and penetrated by chlorite crystals. The chlorite is later than chalcocite and covellite. Fig. 7 shows very plainly that the chlorite is later than covellite. This photograph was taken with a red screen (Wratten A) to bring out the covellite, and so the chalcocite does not show plainly. In Fig. 8, bornite has been altered to chalcocite along crystallographic directions and chlorite is later than chalcocite as well as bornite, for it cuts them indiscriminately. Very narrow rims of chalcocite occur along the chlorite laths where they are in contact with bornite, furnishing evidence of a second generation of chalcocite. This shows faintly in Fig. 8 (near the center).

A specimen from No. 1 tunnel is illustrated by Fig. 5. The lath-shaped crystals penetrating the bornite are colorless chlorite but sericite also occurs in the same relation. The chalcocite here is later than the chlorite, and the bornite-chlorite boundaries have served as capillary channels for chalcocite-bearing solutions. The fact that the center of the veinlets is often occupied by quartz is an indication of the action of supergene solutions as is also the fact the chalcocite rims are sometimes bordered by melaconite. As further evidence of the supergene origin of the chalcocite, No. 1 tunnel is well within the oxidized zone determined by Mr. H. W. Turner. (See Fig. 92 of paper cited.)

Fig. 2 represents a polished section of a very rich copper ore (Cu = 43.9 per cent.) which occurs along a leached zone in No. 5 tunnel (No. 39 of Fig. 91 of paper cited). The sericite has replaced bornite, but it is evident that the chalcocite is a later introduction. As evidence that chalcocite formation is independent of sericitization, note that chalcocite occurs around minerals other than sericite which are mostly hematite. The chalcocite is probably due to an advanced stage of alteration brought about by supergene solutions. The alteration to chalcocite along crystallographic directions of the bornite is very marked in this advanced stage.

Two periods of chalcocite enrichment are well marked in the Engels ores, hypogene chalcocite formed before the sericite, and supergene chalcocite after the sericite. As sericite antedates the supergene chalcocite and is independent of it, the sericite is in all probability a hydrothermal mineral.

OOKIEP, SOUTH AFRICA.

Sericite was also observed cutting into chalcopyrite anhedra in thin sections of magmatic ores from the East Mine at Ookiep, Namaqualand, South Africa kindly furnished me by Dr. A. W. Rogers, Director of the Geological Survey of South Africa. Here the chalcopyrite is a magmatic mineral and there is nothing to determine how much later the sericite is.

SILVER PEAK, NEVADA.

Spurr[11] in discussing alaskite from Silver Peak, Nevada, concludes that sericitization of the feldspars "took place when the magma was partially consolidated and before the deposition of the remainder (of the feldspar) which formed the second generation." This seems very improbable, for it practically makes sericite a magmatic mineral. There seems to be no definite proof that the sericitization has taken place before the consolidation of the magma. For one thing the evidence of two generations of orthoclase is not conclusive. It may be that what is called fresh orthoclase, "*o*" of Fig. *A*, pl. XX. of Spurr's report, is plagioclase (andesine—oligoclase) cut so that twinning does not show. It is a well-known fact that some feldspars are altered while other feldspars in the same rock are unaffected. The gradation in the size of the crystals possibly indicates that the alteration began with coarse muscovitization, the crystals becoming smaller and smaller as the temperature gradually decreased, finally ending with sericitization.

[11] Professional Paper 55, U. S. Geol. Surv., p. 107 (1906).

SERICITE ASSOCIATED WITH CONTACT METAMORPHIC ORES.

Stewart[12] describing the Silverbell, Arizona, contact deposits, stated that the sericite of the intrusives was formed at the same time as the silicates (garnet and wollastonite) of the contact zone, but earlier than the sulphides (pyrite and chalcopyrite) of the contact zone. The criteria for this conclusion are not given. The statement may well be doubted, for Lindgren has shown that at Morenci hydrothermal metamorphism (sericite present) is later than contact metamorphism (sericite absent).

Umpleby[13] mentions sericite in the wall rock of contact deposit at Mackay, Idaho, but ascribes it to hydrothermal alteration.

SERICITE IN HIGH TEMPERATURE VEINS.

Sericite has been described from the walls of pipe-like tin-bearing veins of south Africa.[14]

At Silver Mines, Madison county, Missouri, Haworth[15] found sericite intimately associated with topaz in the wall rocks of a vein containing galena, wolframite, zinnwaldite, fluorite, and quartz.

A specimen from the Bryan mine, Missoula county, Montana, obtained from Professor D. C. Bard, of Butte, consists mainly of quartz with galena and a little tourmaline. This must belong to the lead-tourmaline type of veins recently described by Knopf.[16] The galena replaces quartz and sericite replaces galena. The sericite crystals are in approximately parallel position. This indicates its development under pressure or stress.

Among the copper-tourmaline deposits the Cactus mine, San Francisco district Utah, is prominent. Butler[17] places the sericite of the monzonite of the Cactus mine near the beginning of mineralization and before the development of tourmaline and hematite. He says:

[12] *Trans. Am. Inst. Min. Eng.*, Vol. 43, p. 240 (1912).
[13] Econ. Geol., Vol. 9, p. 321 (1914).
[14] Ferguson and Bateman, Econ. Geol., Vol. 7, p. 235 (1912).
[15] Missouri Geol. Surv., Vol. 8, p. 158 (1895).
[16] Econ. Geol., Vol. 8, p. 105 (1913).
[17] Professional Paper 80, U. S. Geol. Surv., p. 121 (1913).

"The sericitization of the monzonite must have been nearly completed before the deposition of the tourmaline, as it is hardly probable that the solutions which brought in the tourmaline could have penetrated and altered the wall rock to any considerable extent without depositing tourmaline."

This is simply an argument that sericite and tourmaline were not simultaneous, but as far as the evidence goes sericite may have been later than the tourmaline. If the words sericite and tourmaline are interchanged and tourmalinization substituted for sericitization in the above quotation, the argument is equally effective.

Sericite is also present in the gold-tourmaline veins of Meadow Lake, Nevada county, California, described by Lindgren.[18]

Sericite occurs in the Passagem lode in Brazil which Hussak regarded as a pegmatite dike. Derby[19] regards it as a pegmatite that has been fractured and subsequently mineralized by sulphides. In regard to the sericite he says:

"The fissures of the fractured quartz-feldspar rock are here of considerable width and the filling is exclusively of tourmaline with only here and there a small crystal of pyrite. The feldspar is completely sericitized and it is clear that the effect was produced by the agent that introduced the tourmaline rather than the one that brought in the metallic sulphides."

As far as the evidence goes the sericitization may have been contemporaneous with pyritization or even later.

In the gold-telluride veins of western Australia sericite is a prominent mineral. In a thin section from a typical specimen from this district (mine unknown), sericite proves to be later than pyrite, which in turn is later than chlorite.

In the gold-quartz veins occurring in albite-diorite at the Treadwell mine, Alaska, which form a connecting link between the high temperature veins and those formed at intermediate deposits, sericite occurs as a metasomatic alteration of feldspars.

[18] "Mineral Deposits," p. 656.
[19] *Amer. Jour. Sci.* (4), Vol. 32, p. 185 (1911).

SERICITE IN DEPOSITS FORMED AT INTERMEDIATE DEPTHS.

In ore-deposits formed at intermediate depths, sericite reaches its greatest development. The wall-rocks are often converted into altered products containing from 40 to 60 per cent. or more of sericite.

GOLD-QUARTZ VEINS OF CALIFORNIA.

In the gold-quartz veins of the Sierra Nevada, California, sericite is common, especially in the wall-rocks as emphasized by Lindgren.

In a pyritized rock containing albite crystals in cavities from the Harvard mine, Jamestown, Tuolumne county, California, the writer has observed the following successions of minerals: (1) albite, (2) quartz, (3) dolomite, (4) pyrite, (5) sericite. Rhombohedral crystals of dolomite were formed by the metasomatic replacement of quartz. In other spots the sericite cuts dolomite and the sericite is later than pyrite. At one point a slender sericite crystal abuts against the pyrite but has been deflected to one side.

The writer has examined thin sections of a specimen from Calaveras county, California (exact locality unknown), containing large (2 cm.) pyrite cubes. The section consists largely of albite with some quartz, calcite, chlorite, and sericite. The sericite is very prominent and cuts albite, quartz, chlorite, and calcite. As films of sericite coat the surface formed by the pyrite crystals in contact with their matrix the sericite is also later than the pyrite. Acicular crystals of apatite are present in several places. This apatite is not residual from an igneous rock but is undoubtedly a hydrothermal mineral. Similar apatite has been described by Knopf[20] in altered albite-diorite from the Eagle River region, Alaska. The prominence of albite places the gold-quartz veins of the Mother Lode near the southeastern Alaska type that has generally been recognized.

In the mineralogical collection of Stanford University there is a remarkable specimen of sericite from the Longfellow mine, Big

[20] Bulletin 502, U. S. Geol. Survey, p. 37 (1912).

Oak flat, Tuolumne county, California. This is a mass of white to gray sericite scales which was evidently packed in a box when taken from the mine in a wet condition. The plastic mass has taken on the shape of the box. Quartz crystals of various sizes are distributed through the mass. The sericite forms a thin film around the quartz. The sericite is formed after the quartz and has every appearance of being a late development. The apparently pure sericite masses contain small quartz subhedra as shown in thin sections. The quartz has evidently been corroded by the sericite-forming solutions and replaced to some extent, for thin films of sericite are occasionally present within the solid quartz crystals. Three subhedra of quartz noted in the thin section evidently represent the remnants of an original crystal which has been severed by sericite. Two of them extinguish together, while the third has been slightly displaced. The slight displacement during replacement of portions of crystals originally parallel I believe to be a rather common phenomenon. The effect of pressure is evident in the fact that the quartz crystals are in approximately parallel position.

BUTTE, MONTANA.

At Butte sericite is very common in the altered wall rocks as has been pointed out by Weed,[21] Kirk,[22] and Ray.[23] Kirk, especially, devoted a good deal of attention to sericite. He places sericite at an early period of mineralization as may be seen from the following statement.[24]

> "The earliest mineralizers were rich in silica and the components of sericite and pyrite and so filled the rocks with these as to exclude the copper deposition coming later on."

Ray[25] expresses practically the same opinion.

> "The first solution effected sericitization, silicification, and pyritization of the quartz-monozite."

[21] Prof. Paper 74, U. S. Geol. Surv., p. 87 (1912).
[22] Econ. Geol., Vol. 7, p. 35 (1912).
[23] Econ. Geol., Vol. 9, p. — (1914).
[24] *Loc. cit.*, p. 81.
[25] Econ. Geol., Vol. 9, p. 469 (1914).

Ray's conclusion is evidently based upon specimens such as represented by Fig. *B*, Plate X. of his article. A veinlet consisting of sulphides has apparently replaced sericite, but there is a possibility that the sulphides have been replaced by sericite and that the apparent veinlets are simply remnants.

Through the kindness of Mr. Ray I have been able to study some of the Butte specimens. The specimen studied in detail is from the 2,200-foot level of the Speculator mine. A photograph of a polished section is shown in Fig. 12. On casual study the relations of the bornite and chalcocite to the sericite admit of two interpretations (*i. e.*, sericite is earlier than the sulphides or vice versa). It is only by long, careful study that the matter has been settled to the satisfaction of the writer. In Fig. 12 the gray mineral in the left lower corner is sericite. At the left upper corner and in the center are bornite and chalcocite. At the lower right corner there is a little residual pyrite. The invasion of bornite-chalcocite by sericite is unmistakable, and there can be little doubt that spaces now occupied by sericite were once bornite and chalcocite. Notice the irregular bornite-sericite contacts and the remnants of bornite within the sericite. It is also evident that the chalcocite, whatever its origin, was formed before the sericite, as its distribution is in no way related to the present boundaries of the sulphides. The sericite cuts the bornite and chalcocite indiscriminately. In this specimen gashes of late hypogene chalcopyrite which cut the bornite and which were once continuous are now found to be severed by sericite.

Microscopic work proves that the deep-seated chalcocite is the latest of the hypogene minerals in the Butte deposits. Since sericite is later than the chalcocite it follows that the sericite at Butte was formed at, or toward, the close of the hydrothermal period. That it is a hydrothermal mineral at Butte scarcely admits of doubt in view of Kirk's work. As the sericite follows the chalcocite stage we have definite proof that the deep-seated chalcocite at Butte is formed by "upward enrichment." This confirms the opinion expressed by the writer in December, 1913,[26]

[26] Econ. Geol., Vol. 8, p. 781 (1913).

EXPLANATION OF PLATE V.

Thin sections and polished sections from various localities. (*s*, sericite; *q*, quartz; *b*, bornite; *cp*, chalcopyrite; *cc'*, hypogene chalcocite; cc^2, supergene chalcocite; *p*, pyrite.)

FIG. 9. (×90.) Thin section, Copper Flat, Ely, Nevada. Chalcopyrite cut by sericite.

FIG. 10. (×45.) Polished section. Person Consolidated Mine, Virgilina district. Bornite and hypogene chalcocite cut by sericite. Rims of supergene chalcocite between bornite and sericite.

FIG. 11. (×125.) Polished section. "Pay-roll" porphyry, Bingham, Utah. Bornite, supergene chalcocite, quartz, and sericite in altered quartz-monzonite.

FIG. 12. (×140.) Polished section. Speculator Mine (2,200-ft. level), Butte, Montana. Sericite replacing bornite and hypogene chalcocite.

FIG. 9.

FIG. 10.

FIG. 11.

FIG. 12.

which was based upon microscopic work as combined with the geological work of Sales.

BINGHAM, UTAH.

The writer is indebted to Mr. J. J. Beeson, one of his students, for an opportunity to study sections of the disseminated quartz monzonite-porphyry copper ores from Bingham, Utah. Sericite is a prominent mineral in these ores. It occurs as a replacement of feldspars, quartz, and sulphides. Fig. 11 is a microphotograph of a polished section of the "pay roll" porphyry from the Boston Consolidated mine. The transparent minerals are quartz and sericite. The opaque minerals are pyrite, bornite, and chalcocite. The sericite is clearly a replacement of the sulphides. Note that lath-shaped sericite crystals penetrate the sulphides. Contrast the rough sericite-sulphide contacts with the smooth quartz-sulphide contacts. The sericite area in the lower right center of the photograph was once occupied by sulphides. The chalcocite here is an alternation product of bornite. The only question is whether the sericite was formed before the chalcocite or after it. In other specimens Mr. Beeson[26a] has found that sericite crystals which cut bornite and chalcopyrite are bordered by narrow rims of chalcocite with needles of covellite. Occasionally sericite in the center of chalcopyrite has no chalcocite or covellite around it. Mr. Beeson concludes that chalcocite and covellite are later than sericite and that the sericite-bornite and sericite-chalcopyrite contacts have simply furnished capillary channels for the later solutions. A careful study of Fig. 11 also confirms the opinion that the sericite is earlier than the chalcocite. The chalcocite occurs as a wide border around the bornite remnants at the right center of the photograph. This chalcocite border was formed from solutions which surrounded the present sulphide area and not the original sulphide area which is now in part sericite. The chalcocite is almost certainly supergene in origin. In the Bingham disseminated copper ores sericite was formed after the bornite, and this places it toward the close of the hydrothermal period.

[26a] Bull. Am. Inst. Min. Eng., p. 2228 (Nov., 1915).

Euhedral pseudohexagonal crystals of sericite in an altered quartz-monzonite were collected by Mr. Beeson at Bingham.

ELY, NEVADA.

Only a few sections of the disseminated copper ores from Ely have been studied but the evidence, as far as it goes, indicates that the sericite is a rather late hydrothermal mineral. These specimens, which are from Copper Flat, were kindly furnished us by Professor A. C. Lawson, of the University of California. Fig. 9 represents a speck of chalcopyrite in the silicified quartz-monzonite which has been penetrated by sericite.

A specimen of massive pyrite with a thin black film, which is probably chalcocite, has been cracked and the cracks filled with thin films of typical sericite. The sericite is undoubtedly later than the pyrite, but the thin coating of chalcocite is probably later than sericite, and the sericite has furnished capillary channels for the chalcocite-forming solutions.

VIRGILINA DISTRICT.

The copper ores of the Virgilina district of North Carolina and Virginia consist of bornite and chalcocite in a gangue of quartz. Epidote, chlorite, and sericite are also present.

The writer has studied polished sections and thin sections from the Blue Wing mine and from the Person Consolidated mine (formerly the Durgy), Person county, N. C. These were obtained respectively from the California State Mining Bureau and from Dr. T. L. Watson, of the University of Virginia, to whom I would express my thanks.

A polished section of the ore from the Person Consolidated mine is illustrated in Fig. 10. The sulphides are bornite, and chalcocite; the non-metallic mineral is sericite, proved by optical properties in thin sections. Viewed with a lower power lens this section exhibits elongated areas of bornite-chalcocite. The photograph shows one of these almost cut across by sericite. The sericite is later than bornite and also later than the chalcocite, and this is true whether the chalcocite is due to re-

placement of the bornite or to a simultaneous development of bornite and chalcocite. The sericite cuts across the bornite patches and chalcocite areas indiscriminately and the distribution of the two sulphides has no relation to the sericite. There are, however, two generations of chalcocite for the narrow rims of chalcocite around the bornite are undoubtedly later than the sericite.

In further support of the evidence that the sericite is formed between the two generations of chalcocite, Figs. 13–16 from a polished section of a specimen from the Blue Wing mine are presented.

In Figs. 13 and 14 the non-metallic minerals include sericite, chlorite, and quartz. The sericite and chlorite are indistinguishable by the metallographic microscope, but by reflected light with the ordinary microscope they may be distinguished by the fact that the sericite is greenish-white and the chlorite dark green. In thin sections the sericite clearly cuts the chlorite. Two generations of chalcocite are distinguishable, the first generation occurring as irregular areas with bornite, and the second generation as narrow rims around the bornite. A slight color difference in the two kinds of chalcocite can be detected in the lower part of the photographs, but can scarcely be detected in the half-tone. Fig. 14, which is an enlarged view of the lower part of Fig. 13, shows plainly the replacement of the bornite and chalcocite of the first generation by the sericite and also that the second generation of chalcocite is later than the sericite.

Figs. 15 and 16 furnish even better evidence of the same facts. A patch of the earlier chalcocite has been cut across by a veinlet with quartz center which has developed later chalcocite within the bornite. This is conclusive evidence of two generations of chalcocite. This checks the work of Laney[27] who also found two generations of chalcocite in the Virgilina ores. Fig. 16 is a higher magnification of the top of Fig. 15. An irregular chalcocite-bornite area has been truncated by sericite and chalcocite of the second generation has been deposited in rims around the bornite. In Figs 15 and 16 all the non-metallic mineral is sericite.

[27] Econ. Geol., Vol. 6, p. 399 (1911).

EXPLANATION OF PLATE VI.

Polished sections of a specimen from the Blue Wing Mine, Virgilina district, North Carolina-Virginia. (*s*, sericite; *ch*, chlorite; *b*, bornite; *cc'*, hypogene chalcocite; cc^2, supergene chalcocite.)

FIG. 13. (×40.) Bornite and hypogene chalcocite cut by sericite and chlorite.

FIG. 14. (×125.) Magnified view of the lower part of Fig. 13.

FIG. 15. (×40.) Bornite and hypogene chalcocite cut by sericite and supergene chalcocite veinlets with quartz centers. Ruins of supergene chalcocite around bornite.

FIG. 16. (×125.) Magnified view of upper part of Fig. 15.

FIG. 13.

FIG. 14.

FIG. 15.

FIG. 16.

The second generation of chalcocite is probably of supergene origin as definite veinlets occur often with quartz centers. The first generation of chalcocite is almost certainly hypogene in origin.

SERICITE IN DEPOSITS FORMED NEAR THE SURFACE.

In Lindgren's division of ore-deposits formed near the surface by ascending thermal solutions, sericite though usually present in fair quantities is not often abundant. Its place seems to be taken in part by adularia, which is of the same general composition. But at Tonopah, Cripple Creek, Jarbridge (Nevada), Rawhide (Nevada), De Lamar (Idaho), and Silver City (Idaho), and in the Thames district, of New Zealand, sericite occurs with adularia. At Lake City (Colorado), Silverton (Colorado), and Nagyag (Hungary) sericite occurs without adularia. At Lake City, according to Irving and Bancroft,[28] pyrite, silica, and sericite represent the earliest stages of vein formation.

The writer has examined a thin section of an altered rhyolite (or possibly dacite) from Rawhide, Nevada.[29] The orthoclase phenocryst has been partly altered to sericite, while in the groundmass rhombic crystals of adularia occur along with quartz anhedra. Though the sericite and adularia occur together they are probably not formed simultaneously, for they represent different types of alteration. The relative age of the two minerals in the Rawhide specimens can not be determined. Spurr[30] referring to adularia and sericite at Tonopah says:

> "That one of these products is not an alteration product of the other is shown by the fact that they are often intercrystallized, each mineral being perfectly fresh."

But this does not prove that they were formed simultaneously.

There are, however, hints in the literature that sericite may be later than adularia. Lindgren and Ransome,[31] speaking or latite-phonolite in Cripple Creek, say:

[28] Bull. 478, U. S. Geol. Surv., p. 44 (1911).

[29] What was called sericite in an adularia-quartz vein at Rawhide, by the writer (ECON. GEOL., Vol. 6, p. 790, 1911), proves to be calcite.

[30] Prof. Paper 42, U. S. Geol. Surv., p. 227 (1905).

[31] Prof. Paper 54, U. S. Geol. Surv., p. 189 (1906).

"In one place fibers of sericite project into the adularia."

Umpleby[32] in the description of the Parker Mountain district in Lemhi county, Idaho, says:

"Sericite in quartz is probably, in part at least, derived from adularia."

The deposits formed near the surface in connnection with igneous rocks are formed at temperatures ranging from about 50° C. to 150° C., according to Lindgren.[33] The presence of sericite in these deposits, then, is further evidence that it is a rather low temperature mineral, and if, as seems probable, sericite is later than the adularia, there is evidence of still lower temperature.

The occurrence of sericite in these low temperature deposits is of more significance than its occurrence in high temperature deposits such as deep veins and magmatic sulphide ores, for its formation did not necessarily take place along with the deposition of ores and the high temperature gangue minerals. Evidence rapidly accumulating, especially from the microscopic side, makes it certain that often the minerals of an ore deposit are successively formed at gradually decreasing temperatures. This has been brought out by Spurr and Garrey[34] in a valuable paper. The same fact is evident in a study of the Butte ores now being made at Stanford University by Mr. J. C. Ray and a microscopic study of many types of copper sulphide ores has convinced me that it is safe to assume this as a generality.

THE OCCURRENCE OF SERICITE IN METAMORPHIC ROCKS.

Sericite is a common mineral in some kinds of metamorphic rocks, especially certain schists and gneisses. It seems to be the general belief that sericite in metamorphic rocks is the product of dynamic metamorphism. Clarke,[35] speaking of sericitization, says:

"The alteration is most conspicuous in regions where the dynamic

[32] Bull. 528, U. S. Geol. Surv., p. 79 (1913).
[33] "Mineral Deposits," p. 138 (1913).
[34] ECON. GEOL., Vol. 3, p. 687 (1908).
[35] Bull. 491, U. S. Geol. Surv., p. 567 (1911).

metamorphism has been most intense—high temperature; the chemical activity of water and mechanical stress all working together to bring it about."

G. H. Williams[36] says:

"Sericitization is therefore a phenomenon of dynamic metamorphism."

Grubenmann in a recent work[37] on the metamorphic rocks places the sericite-bearing rocks (sericitphyllit, sericitalbitgneise, sericitquartzit, etc.) in the Epi-division formed in the upper zone of metamorphism under conditions of moderate temperature, small hydrostatic pressure, and strong stress.

The only very careful study of sericite in metamorphic rocks that has come to my notice is de Lapparent's[38] paper on some of the French porphyroids. This contribution to our knowledge of sericite is one of the most important that has yet appeared. De Lapparent makes positive statements to the effect that sericite is later than the period of dynamic metamorphism:

"Le séricite dont il est ici question est postérieure à l'époque ou les phénomènes dynamiques se sont produits . . .[39]
et de plus qu'elle n'est
pas un minéral de transformation dynamométamorphique, mais qu'elle est due à la circulation lente des eaux."[40]

Laughlin[41] comes to the conclusion that sericite in a gneissoid alaskite at Lantern Hill, Connecticut, is of later development than the gneissic structure and is not due to dynamic metamorphism.

The writer has examined a thin section of a sericite gneiss from Bonnie Doon near Santa Cruz, California, collected by Mr. C. A. Waring. The two principal minerals are the quartz and sericite. The sericitized areas undoubtedly represent original feldspars. Sericite has also formed at the expense of the quartz and the unknown mineral. It is clear that sericitization was subsequent

[36] Bull. 62, U. S. Geol. Surv., p. 60 (1890).
[37] Die Kristallinen Schiefer, 2d ed., 1910.
[38] *Bull. fr. soc. min.*, Vol. 32, p. 174 (1909).
[39] *Loc. cit.*, p. 215.
[40] *Loc. cit.*, p. 301.
[41] Bull. 492, U. S. Geol. Surv., p. 140 (1912).

EXPLANATION OF PLATE VII.

Thin sections of rocks from Marquette, Michigan (Fig. 17), and Mound House, Nevada (Figs. 18, 19, 20). (*s*, sericite; *q*, quartz; *m*, muscovite; *a*, anhydrite; *g*, gypsum; *c*, calcite.)

FIG. 17. (× 30.) Quartzite with original sand grain (*q*) and second enlargement (*q'*) cut by sericite.

FIG. 18. (× 12.) Anhydrite altering to gypsum with original calcite.

FIG. 19. (× 30.) Sericite in recrystallized gypsum with remnants of original calcite.

FIG. 20. (× 24.) Muscovite in compact gypsum with remnants of original calcite.

FIG. 17.

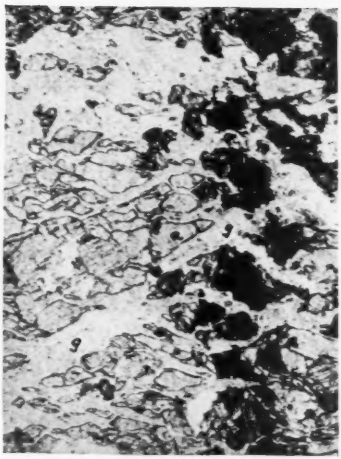


FIG. 18.

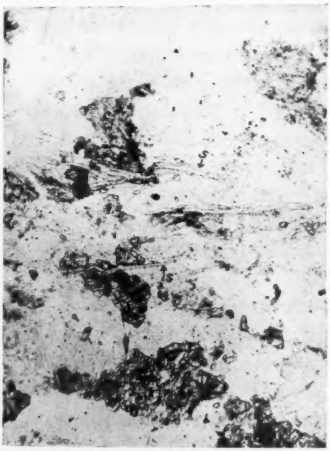


FIG. 19.

FIG. 20.

to the main period of metamorphism at which time the quartz and feldspar were crystallized or recrystallized.

A thin section of graphite gneiss from Hague, New York, also indicates that sericite was a late development in the rock, which consists of quartz, graphite, apatite, and sericitized areas.

A common occurrence of sericite is in quartzites and often sericite is the only mineral present besides quartz. In a quartzite from Marquette, Michigan (Rohn's Lake Superior Collection No. 55) sericite occurs in minute shreds in approximately parallel position. Fig. 17 is a microphotograph of a thin section of this quartzite. In the center is an original rounded sand grain with secondary enlargement of quartz on the lower side. The sericite occurs in shreds at the top and bottom of the quartz grain. It is evident that sericite was formed after the secondary enlargement and after the introduction of silica. The sericite, then, is a late development in the rock but must have formed under pressure as indicated by the parallel position of the individual crystals.

SERICITE IN METAMORPHIC ROCKS WITH ORES.

Several occurrences of sericite in metamorphic rocks which also contain ores have been studied.

In a schistose sphalerite ore from near Webb station, Mariposa county, California, sericite replaces sphalerite, pyrite, and undetermined sulphides.

In the foothill copper belt of California, which is just west of the Mother Lode, pyrite and other sulphides occur in schists, which are often sericitic. In specimens from the Ione Copper mine, near Ione, collected by Mr. A. T. Schwennesen, pyrite is later than sericite and quartz. The sericite is in part due to replacement of the quartz. This quartz represents a phenocryst of an original rhyolite or quartz-porphyry which has been converted into a sericite-schist. Ore deposition is in this case later than the metamorphism; pyrite which has replaced a lens of quartz cuts across a shred of sericite.

In the Snowstorm mine, near Mullan, Idaho, tetrahedrite occurs disseminated through a sericitic quartzite. The tetrahedrite is

later than sericite, but the latter was evidently formed during the metamorphic period which preceded ore deposition.

In the Ione and Snowstorm specimens the sericite apparently has no connection with ore-deposition, and so these are exceptions to the general rule found in other deposits in which sericite is later than the sulphide ores. In the complex sphalerite ore from Webb late hydrothermal action was probably subsequent to metamormorphism.

SERICITE IN SCHISTOSE GYPSUM FROM MOUND HOUSE, NEVADA.

In a large gypsum quarry at Mound House, Nevada, the writer found that some of the gypsum contains sericite. This occurrence, which was recently described by the writer,[41a] may possibly throw some light upon the temperature at which sericite forms and so will be described in detail.

Anhydrite occurs at several points on the main quarry floor, and hand specimens show clearly that the transformation of anhydrite into gypsum has occurred. Microscopic study conclusively proves this point. The anhydrite is a grayish-white crystalline rock and contains a little calcite in anhedral crystals. Most of the gypsum is a compact grayish-white, massive rock. The thin sections show irregular, closely interlocking anhedra with suture-like boundaries. A little calcite is present and it is exactly like the calcite in the original anhydrite. Fig. 20 is a photograph of a thin section of the compact gypsum and Fig. 18 one that shows the anhydrite partially altered to gypsum.

A few pieces of crystalline limestone were found loose in the quarry and at one point an impure crystalline limestone containing phlogopite, feldspar, pyrite, and several undetermined silicates, were found in the gypsum. Dark colored patches proved to contain tourmaline. The phlogopite-bearing rock probably represents impure limestone layers or inclusions in the original anhydrite. These silicates must be the result of metamorphism. The anhydrite itself is a metamorphic rock and was probably formed from a sedimentary bed of anhydrite.

[41a] *School of Mines Quarterly*, Vol. 36, p. 130 (1915).

The most interesting rock, however, is a somewhat schistose gypsum containing sericite and a little pyrite. The schistose structure is due to a more or less parallel arrangement of gypsum subhedra and to small elongate scales of sericite which have developed along the schist plane and are plainly visible to the naked eye. Fig. 19 is a photograph of a thin section which with crossed nicols bears a strong resemblance to a figure of micaceous quartzite from Hoosac Tunnel figured by Leith.[42] The gypsum is evidently the result of recrystallization under stress. As evidence of the recrystallization of the gypsum the following are noted: (1) Increase in the size of the crystals, (2) more or less parallel position of the crystals, (3) subhedral crystals instead of the original interlocking anhedra, (4) lack of strain phenomena.

The sericite is either a residual mineral from the anhydrite stage or it also is the result of recrystallization under pressure. The sericite occurs for the most part between the gypsum crystals, but in some cases it apparently cuts the gypsum. This, however, may be the result of the recrystallization of gypsum around the sericite. The calcite is penetrated by the sericite and in a few cases sericite curves around the calcite. While no sericite or muscovite was found in the original anhydrite, thin sections of the compact gypsum show a few small muscovite crystals (Fig. 20) which are different in habit from the sericite, being stouter. As the compact gypsum is the direct hydration product of the anhydrite this muscovite is probably a remnant from the metamorphic anhydrite stage at which time a rather high temperature must have prevailed. This muscovite probably furnished the material for sericite and the sericite is simply recrystallized muscovite. Taking all the facts into consideration, there can be little doubt that the sericite was formed during the recrystallization of gypsum.

The alternative is that the sericite is a residual mineral from the anhydrite stage, for it is a well-known fact that sericite is often persistent under weathering conditions. Against the view that the sericite is residual are the following arguments: (1) The sericite is only found in the schistose, recrystallized gypsum.

[42] Bull. 239, U. S. Geol. Surv., plate IX. *B* (1905).

(2) The compact gypsum contains muscovite of different habit from sericite. (3) The sericite crystals are in parallel position in the recrystallized gypsum while the muscovite crystals are not parallel in the compact gypsum. (4) The sericite, but not the muscovite, penetrates calcite.

If, as seems probable, sericite is a hydrothermal mineral formed during the recrystallization of gypsum, the necessary heat must have had some effect upon the gypsum. The effect of heat upon gypsum has been studied by Le Chatelier, van't Hoff, and Davis. Three compounds are formed according to the conditions of the experiment. These compounds are anhydrite, soluble anhydrite (a modification of calcium sulphate), and the half hydrate, which is $CaSO_4.\frac{1}{2}H_2O$.

If the dehydration takes place below 107.2° C., soluble anhydrite is formed, according to van't Hoff, and this may occur at a temperature as low as 63.5° C. The resulting product is very hygroscopic and takes up water to form gypsum. Above 107.2° C. gypsum is converted into half hydrate. The half hydrate, however, is very unstable and is reconverted into gypsum, which accounts for the fact that it does not occur in nature. Total dehydration of gypsum occurs at about 190° C. even in the presence of moist air. Heated above this temperature, so-called "dead burned" gypsum, which only sets with water with extreme slowness, is produced.

From the above data it seems almost certain that the sericite at Mound House was formed at a temperature below 190° C. The compact gypsum formed directly from anhydrite was probably converted into the half-hydrate, which in turn took up water to form gypsum while still under pressure. This is probably the cause of the recrystallization of the gypsum. If a temperature greater than 190° C. had even been reached, the gypsum would have been converted into "dead-burned" gypsum which is the equivalent of anhydrite.

SERICITE A LOW TEMPERATURE MINERAL.

The study of both thin sections and polished sections of a number of ores of varying type and wide distribution proves that seri-

cite is formed after the hypogene sulphides. The only exceptions to this noted by the writer were several ores which occur in metamorphic rocks and in these cases the sericite belongs to the metamorphic period and so has connection with the ore deposition.

The microscopic study of various types of ores convinces me that in the great majority of cases ore-minerals, especially sulphides, are formed later than the gangue minerals, which are mostly silicates and silica. This is even true for the magmatic sulphides as shown by the writer.[43] The only hypogene silicates later than the sulphides that I have been able to find are chlorite, sericite, and tremolite. There may be some exceptions, but I believe further study will prove the truth of the statement that the sulphides are in general later than the hypogene silicates.

When we have the evidence that a series of hypogene sulphides have been formed at gradually decreasing temperature as at Butte, and that sericite is later than these sulphides, we are forced to the conclusion that sericite is formed at a very late stage in mineralization. In fact, I can find no evidence that any hypogene mineral is later than sericite.

Of course there is not definite evidence that sericite is a late, low temperature mineral in every occurrence studied, for often only a few minerals occur, and the intermediate stages of mineralization are lacking.

On careful analysis the published evidence that sericite is contemporaneous with the sulphides or is formed at an early period of mineralization is not convincing; *i. e.*, there is no clear evidence supported by microphotographs.

Probably few will doubt that in some cases sericite is a low temperature mineral. The next question that presents itself is the temperature range of sericite. Dr. F. B. Laney and Professor C. F. Tolman, jr., in conversation with the writer, while admitting his microscopic evidence, both expressed the opinion that sericite ranges from rather high temperature to low temperature. While further study is necessary to settle this point it is worth while to consider all the evidence bearing on this point.

[43] ECON. GEOL., Vol. 9, p. 389 (1914).

For my part, I believe that sericite has a rather restricted range. Its occurrence in high temperature and medium temperature deposits is easily accounted for, if we assume gradually decreasing temperature. Only by making such an assumption can we account for the series of replacements of one mineral by another which the microscope proves to have taken place.

The only serious objection to the invariable low temperature origin of sericite is one suggested by Professor Tolman, which is the failure of the earlier solutions to effect alteration of the wall rocks. This brings up an interesting point, but one difficult to settle. One possible explanation is that the period of vein formation and ore-deposition is a relatively brief one, even though the stages are often well marked, and that the reactions involved in sericitization are rather sluggish. At any rate the microscopic examination of ores which are typical and not exceptional types, proves that the sericitization did not take place until towards the close of the hydrothermal period. The explanation remains to be found.

IS SERICITE A PRODUCT OF WEATHERING AND STATIC METAMORPHISM?

The proof that sericite is a rather low temperature mineral makes it necessary to inquire into its possible origin from cold meteoric waters.

Paige[44] finds sericite later than turquois in the Burro mountains (N. M.) deposit, and considers that it may be formed by downward circulation of carbonated waters.

Hickling[45] in discussing the china-clays of Cornwall says:

> "Atmospheric weathering is the cause of the 'kaolinization' of the granite. Secondary muscovite (sericite) represents the first stage of the process and is a normal product of the weathering feldspars."

Lindgren[46] believes that this sericite is due to previous alteration by thermal waters and also expresses the opinion:

[44] ECON. GEOL., Vol. 7, p. 388 (1912).
[45] *Trans. Inst. Min. Eng.* (London), Vol. 36, p. 31 (1908–9).
[46] "Mineral Deposits," p. 299, 305 (1913).

"It is not believed that muscovite or sericite results from weathering."

As arguments against the idea that sericite is the product of weathering the following may be mentioned.

The weathering of various igneous and metamorphic rocks results in a loss of potash (K_2O) which amounts to as much as 92 per cent. in some cases. This is shown conclusively by Merrill.[47] Sericitization on the other hand results in a gain of potash.[48]

Kaolinite, not sericite, is produced by the action of carbonated water upon feldspars.[49]

Although often rather resistant, muscovite and sericite are slowly attacked in the zone of weathering.

Sericite is often absent in weathered granites. This is of more significance than the presence of sericite in certain weathered granites, for the sericite may have been formed by a hydrothermal process prior to weathering. In a suite of granites, granite-pegmatites, and granite-aplites from the Headquarter mountains near Granite, Oklahoma, weathering is evident in all specimens which were taken from the surface boulders and not from quarried material. The feldspars are much altered but no sericite could be found. The alteration product is an indefinite white, almost opaque, substance which is probably kaolinite or possibly its colloidal equivalent. The alteration begins on the outside of the feldspar and proceeds toward the interior. Sericitization on the other hand usually begins in the interior of the feldspar.

Lindgren[50] believes that sericite found in various rocks of the Clifton-Morenci district, Arizona, remote from the ores, was formed by what he calls "common hydrometamorphism"[51] which he defines thus: "This which is also described as static metamorphism, includes the changes effected under the influence of ordinary percolating waters of a moderate depth, but distinctly below the zone of active oxidation."

[47] "Rocks, Rock-weathering and Soils," p. 185 et seq.

[48] Steidtmann, ECON. GEOL., Vol. 3, p. 381 (1908).

[49] Müller, "Tschermak's Min. Mitth.," Jahrg. 1877, p. 47.

[50] Prof. Paper 43, p. 125 (1905).

[51] This term was first used by Lindgren in his monograph on the "Gold-Quartz Veins of Nevada City and Grass Valley" (17th An. Rep. U. S. Geol. Surv., pt. 2, p. 91, 1896).

If sericitization is a late stage of mineralization, there is no reason why it should invariably follow metallization, nor, on the other hand, why it should necessarily be preceded by metallization. Hydrothermal alteration is assuredly not always accompanied by ore-deposition. For it is a well-known fact that most quartz veins are barren.

It must be recognized that some minerals, especially those in sedimentary rocks, are formed below the zone of oxidation by static metamorphism or diagenesis. Andrée[52] limits the term diagenesis to changes brought about by vadose or connate solutions which do not introduce materials from an extraneous source. The process, then, is one mainly of recrystallization and induration, at least for the sedimentary rocks. With the limitation that no material is introduced from outside sources it may be doubted whether any changes take place in the silicates of igneous rocks below the zone of oxidation. There remain to be considered changes caused by meteoric waters in advance of oxidation but there are few available data on this phase of metamorphism.

In a microscopic study of copper ores from the Engels mine in Plumas county, California, the writer has given special attention to this point. The original ore consists of magmatic bornite and chalcopyrite disseminated through a norite-diorite.. As far as can be ascertained, the only minerals formed in advance of oxidation by descending solutions are chalcocite and veinlets of quartz. Sericitization is independent of, and preceded by, the formation of supergene chalcocite. The sericite occurs in sharp, well defined crystals of appreciable size and not in the indefinite scales and fibers so characteristic of this mineral. This in itself is an argument against the supergene origin of the sericite, for if it does occur as a supergene mineral one would expect to find it in crystal aggregates still finer than those of hydrothermal origin.

There is no clear evidence that sericite is formed by meteoric waters either in the oxidized zone or below it, but more observations are needed before positive statements can be made.

A plausible explanation of why sericite is not formed by meteoric waters is that hydrostatic pressure or stress is necessary

[52] *Geol. Rundschau,* Bd. II., pp. 61–74, 117–130.

for the development of sericite. If fluorine is required for the formation of sericite as is suggested by Spurr,[53] pressure may be necessary to retain the fluorine. This does not necessarily mean that sericite contains fluorine. For the fluorine may simply act as a catalyzer.

THE HYDROTHERMAL ORIGIN OF SERICITE.

The greatest development of sericite is in altered wall-rocks of ore-bearing veins and in metamorphic rocks. The ores we know are, for the most part, hydrothermal in origin and de Lapparent's[54] work on the porphyroids indicates that the sericite in metamorphic rocks is not the product of dynamic metamorphism, but is due to the slow circulation of solutions, which means that it is hydrothermal. The hydrothermal origin of sericite is emphasized by some of the recent students of ore-deposits among whom are Lindgren,[55] Kirk,[56] and Steidtmann.[57]

Among arguments in favor of the hydrothermal origin of sericite the following may be advanced:

Hydrothermal alteration usually involves a marked increase in the potash content.

The occurrence of sericite suggests that it develops only under conditions of moderate pressure or stress.

Sericitization in several ore-deposits precedes the formation of supergene chalcocite.

Kaolin near the surface is often found to pass into sericite at depth.

SUMMARY AND CONCLUSIONS.

Sericite, though very similar to, if not identical with, muscovite in chemical composition, may be considered a distinctive mineral and not simply a variety of muscovite.

Sericite not only replaces silicates but also various sulphides

[53] Prof. Paper 42, U. S. Geol. Surv., p. 232 (1905).
[54] *Loc. cit.*
[55] "Mineral Deposits," p. 299 (1913).
[56] Econ. Geol., Vol. 7, p. 67 (1911).
[57] Econ. Geol., Vol. 3, p. 381 (1908).

such as pyrite, chalcopyrite, bornite, chalcocite, covellite, galena, and sphalerite.

Sericite is a rather low-temperature mineral formed at, or towards, the close of the hydrothermal period. Few, if any, of the hypogene minerals are later than sericite.

Sericite is later than hypogene chalcocite, but earlier than supergene chalcocite.

Sericite in metamorphic rocks is also formed at a late stage equivalent to the hydrothermal stage of ore-deposition.

Sericite apparently does not form in the zone of weathering and probably not in the zone of static metamorphism.

A METALLOGRAPHIC STUDY OF THE COPPER ORES OF MARYLAND.

ROBERT M. OVERBECK.

INTRODUCTORY.

Copper has been mined in Maryland since pre-Revolutionary days. Before the discovery of the large western deposits and the consequent drop in the price of copper, copper-mining was an industry of some importance in the State. Eight mines in all have been worked at one time or another: six of these were abandoned at least twenty-five years ago; and one is still worked, but only occasionally. Although no figures are available giving the total output of copper from the state, a production of $1,750,000 from one of the mines over a period of twenty-five years will give a general idea of the former importance of copper-mining in Maryland.

An investigation of these deposits was undertaken with the hope that a microscopic examination of the ores might reveal something of the genesis of the deposits, and also add something to the general knowledge of the genesis of copper ore. In particular the object of the work was to study the structural relationships existing among the copper minerals in the ores, especially with regard to the question of the primary or secondary occurrences of bornite, chalcopyrite, and chalcocite. Certain difficulties connected with the work prevented its being as complete as could be desired, the chief of which were the impossibility of underground observation and the scarcity of good material. A close study of thin sections of country and of vein rock, however, and a very careful search of the mine dumps eliminated some of these difficulties.

The description of the deposits will be taken up in the follow-

ing order: (1) The Bare Hills mine; (2) the Eastern Carroll County mines, comprising the Patapsco mine, the Mineral Hill mine, and the Springfield mine; (3) the Frederick County mines, comprising the Liberty Mine, and the New London, or Linganore mine.

DETAILED DESCRIPTION OF MINES.

Baltimore County Mine, Bare Hills Mine.

The Bare Hills copper mine is located about 4 miles north of Baltimore on the northern outskirts of the suburb of Mt. Washington. A small mine dump is all that remains to mark the site of the old mine, last worked about thirty years ago.

The deposit, according to old descriptions, was in a vein which carried chalcopyrite, bornite, and magnetite. Unfortunately the material on the mine dump has so succumbed to attacks of the weather that ore and gangue minerals sufficiently fresh for microscopic study could not be obtained.

The deposit occurs in a general region of hornblende schist, probably an altered gabbro. A few hundred yards to the east lies a small serpentine mass that has been intruded into the schist. The ore is apparently in a vein conforming in strike to the schistosity of the rocks; and, as far as can be judged from general relationships and from the kind of material found on the dump, the deposit is similar in all respects to the copper occurrences of eastern Carroll County, which will be taken up in detail in the following pages.

The Eastern Carroll County Mines: the Finksburg-Sykesville Belt.

If a line be drawn on the map from Finksburg, Carroll County, in a direction S. 35° W., most of the copper mines and prospect holes giving evidence of copper will lie very close to this line. At the northern end is the Patapsco mine at Finksburg; 4½ miles southwest of Finksburg is the Mineral Hill mine, between the two is one prospect hole showing copper; 1 mile southwest of Mineral Hill an opening shows the presence of chalcopyrite, and a half

mile farther on at the point where the line crosses the state road, copper stains were noticed when the road was being built; a little farther on are a number of prospect holes, still on the same line. To include the southernmost deposits (those in the neighborhood of Sykesville), the line must be allowed to swing slightly to the south. If this is done, the Carroll mine and the Springfield mine, together with the intervening openings, fall into place. Several former iron mines are also found in Howard County on the southern extension of this belt.

An interesting feature of this belt of deposits is the relationship between the iron and the copper ores. In general iron ore is present in all the mines. On the southernmost extension of the belt in Howard County iron was mined, but no copper. The Springfield mine was opened as an iron mine; at a depth of between 60 and 100 feet enough chalcopyrite came in to change the character of the ore to a copper ore. The iron in the outcrop was in the form of specularite, but with depth it seems to have been largely magnetite. At Mineral Hill both iron and copper were found, but copper was much nearer the surface than was the case at Springfield. Magnetite predominates here. At the Patapsco mine copper ore occurs at the surface, together with much magnetite.

Patapsco Mine.

Location.—The Patapsco mine, the most northern of the eastern Carroll County group of mines, lies at the eastern end of the village of Finksburg, a few yards north of the Westminster turnpike. The nearest railroad station is Falls, on the Western Maryland Railroad, 23 miles from Baltimore. A small mine dump and a depression over the old shaft are all that remain to mark the site of the mine.

Geology.—All the copper mines of Maryland lie in that part of the state known geologically as the Piedmont Region. The characteristic features of Piedmont geology are so well known that a discussion of them here would be out of place. The rocks, in general, consist of schistose sedimentary and igneous rocks; and of unmetamorphosed igneous rocks intruded into the schists.

The prevailing rock of the general region in which the Patapsco mine lies is a quartz mica schist which, in the immediate neighborhood of the mine, has most of the characteristics of a phyllite. A thin section of this rock shows it to consist largely of fine-grained anhedral quartz with much biotite, sericite, garnet, and magnetite. The nature of the minerals present and their relationships suggest at once an original sedimentary origin for the schist. An examination of the rock making up the mine dump, however, shows it to be of an entirely different character from that of the country rock; for here are exposed amphibole and biotite schists. The contact between these two kinds of rock is effectually concealed, although the occurrence of weathered amphibole schist on the road-side about 100 yards east of the mine shows the existence of this rock for the distance mentioned at least.

A microscopic study of the rocks found on the mine dump was undertaken in order to determine, if possible, their nature before metamorphism. A thin section of the biotite schist showed it to consist entirely of flakes of greenish biotite in an unaltered condition. There are several types of hornblende schist, one of which consists almost entirely of common hornblende with small amounts of magnetite and biotite; and another of which is made up of common hornblende, zoisite, some plagioclase feldspar, quartz, and much epidote which replaces the hornblende and is evidently a product of the decomposition of feldspar and hornblende.

The rock appears to be derived from a basic igneous rock, and is probably a metagabbro. Aside from the schists, a small amount of pegmatitic material was found, which from its unaltered nature and from its relation to the schists evidently had its origin after the schists were formed. It has a miariolitic texture, and crevices which intersect it are lined with zeolites.

About all that can be said on the geological structure of the region around the mine is that the schists have a general strike N. 30° E. with a nearly vertical dip that varies from east to west.

Type of Deposit.—The copper ore, according to Tyson[1] who

[1] First Report of Philip T. Tyson, State Agricultural Chemist, to the House of Delegates of Maryland, Doc. E, February 12, 1860.

was writing at the time the deposit was being worked, was found in a *"true vein"* that "became thinner, or pinched off" with depth. The ore mined consisted of chalcopyrite, bornite, chalcocite, and carrollite, together with their oxidation products, and much magnetite.

Description of the Ore.—The description of the ore will be considered under two heads: first, the relation of the ore minerals to gangue minerals as shown in thin sections; and, second, the relations that exist among the opaque minerals as revealed by the study of polished sections.

The copper-bearing minerals—chalcopyrite, bornite, and carrollite—were found both in the biotite and the hornblende schists, and in the pegmatitic material: chalcopyrite being found in both schist and pegmatite; bornite being confined largely to the pegmatite rock; and carrollite[2] to the schist near the contact with pegmatite. Magnetite is present in the schist in large amounts closely associated with the copper minerals. An examination of the thin sections shows that, with the possible exception of some magnetite, all the opaque minerals are later than the transparent minerals present. The magnetite appears to be of two ages: part of it, occurring as sharp crystals and as grains in hornblende, being at least as old as the hornblende; and part of it being decidedly later than the hornblende. Fig. 1, shows chalcopyrite and bornite replacing hornblende, chlorite, and calcite; Fig. 2, is an excellent illustration of the replacement of epidote and feldspar by bornite.

A microscopic examination of polished sections of the ore brings out the relationships that exist among the ore minerals, and between ore minerals and gangue. The opaque minerals will be treated here in the approximate order in which they came out of solution.

Magnetite.—Magnetite, the earliest of the opaque minerals to crystallize, occurs in closely packed grains and in sharp or slightly rounded crystals. Although, as pointed out above, the magnetite is of two distinct ages of formation, by far the greater part is

[2] Carrollite—$CuCo_2S_4$, a very rare cobalt mineral first described from the Patapsco mine.

EXPLANATION OF PLATE VIII.

FIG. 1. *The Mineral Hill Mine.* (×47.) Thin section showing chalcopyrite and bornite (both black) replacing hornblende (the mass of the slide) and chlorite (large light flake near upper left-hand corner).

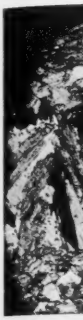
FIG. 2. *The Patapsco Mine.* (×47.) Thin section showing replacement of epidote (rough surface) and feldspar (upper part of picture) by bornite (black).

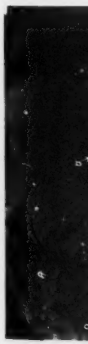
FIG. 3. *The Mineral Hill Mine.* (×60.) Polished section. Inclusions of bornite (*b*) and chalcocpyrite (*cp*) in a large magnetite (*mt*) crystal. The presence of both bornite and chalcopyrite in the same inclusion in the magnetite crystal shows their contemporaneity. Note the parallel or perpendicular arrangement of the rod-like inclusions. (Cf. Fig. 12.)

FIG. 4. *The Patapsco Mine.* (×320.) Polished section. Chalcopyrite (*cp*) is shown here in contact with a magnetite (*mt*) crystal. The corrosion and the rounding of the corners of the magnetite crystal indicate that the magnetite crystallized before the copper minerals came out of solution.

FIG. 5. *The Patapsco Mine.* (×375.) Polished section. This section shows a triangular inclusion in sphalerite (*se*), of bornite (*b*) and chalcopyrite (*cp*). Graton and Murdoch call attention to such triangular inclusions of chalcopyrite in sphalerite and suggest that they are sphenoidal crystals of chalcopyrite. The inclusion in this case is probably not a crystal. Covellite (*cv*) and chalcocite (*cc*) are seen replacing the sphalerite.

FIG. 6. *The Mineral Hill Mine.* (×70.) Polished section. Typical ore consisting of chalcopyrite (*cp*), bornite (*b*), magnetite (*mt*), and secondary chalcocite which replaces bornite and chalcopyrite along crevices. The chalcopyrite and bornite show typical primary relationships.





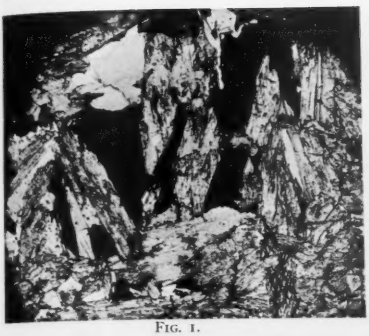


FIG. 1.

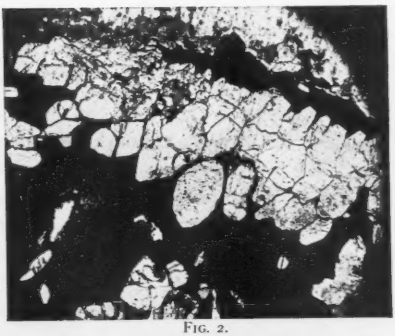


FIG. 2.

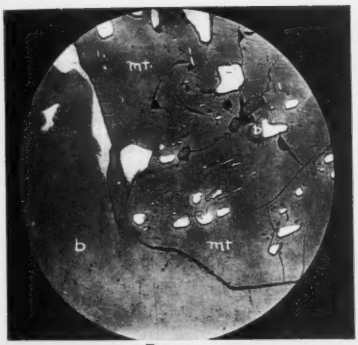


FIG. 3.

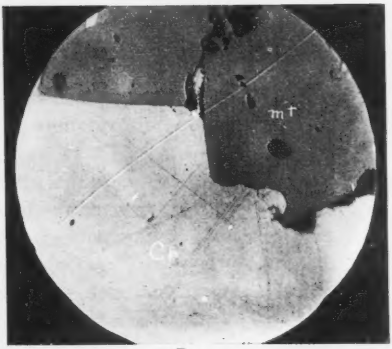


FIG. 4.

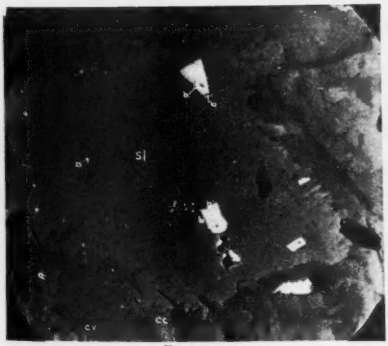


FIG. 5.

FIG. 6.

later than the schist in which it is found. A typical sample of the copper ore in which magnetite is present shows the following arrangement of minerals: first, a mixture of magnetite and schist in which the magnetite is both earlier and later than the gangue minerals; then a band of closely packed rounded grains of magnetite; next, a band of large well-formed magnetite crystals which are surrounded, or partly surrounded, by bornite and chalcopyrite, and which include numerous grains of the copper-bearing minerals. The facts, then, concerning the occurrence of the magnetite warrant the conclusion that it was the first of the opaque minerals to crystallize, and that some of it at least crystallized out of copper-bearing solutions. Fig. 3, shows inclusions of chalcopyrite and bornite in magnetite. The rounding of several of the crystals that are in contact with the copper minerals suggests a slight change in physical chemical conditions just after the crystal was formed. Fig. 4, is at a contact between chalcopyrite and magnetite, showing rounding and corrosion of the magnetic crystal.

Specularite.—Specularite, occurring in a narrow band, was noted in only two places, both of which were in the pegmatitic ore. In one case it distinctly replaces quartz; in the other case, in which it is surrounded by copper minerals, it is greatly corroded. Its relations to magnetite could not be determined, although it is evidently earlier than the copper-bearing minerals.

Carrollite.—Carrollite ($CuCo_2S_4$) occurs in such small amount and in such unfavorable surroundings that little that is definite can be said about it. It is evidently later than magnetite, but its relations with bornite and chalcopyrite are somewhat uncertain. The fact that it has roughly cubical outline, and that in one case chalcopyrite seems to be included in it would indicate that it is somewhat earlier than the other copper minerals present. The crystals are much fractured; chalcocitization has taken place along the fractures.

Sphalerite.—Since sphalerite occurs here in only very minor amounts, its discussion will be reserved for the Mineral Hill ores, where its relations to the other minerals can be more clearly observed. In the Patapsco ore it seems to be restricted to the peg-

matitic material, and occurs as irregular masses that have been altered largely to chalcocite and covellite. Fig. 5, shows sphalerite altering to chalcocite and covellite, and including chalcopyrite and bornite. The sphalerite is earlier than the chalcopyrite and bornite.

Chalcopyrite and Bornite.—Chalcopyrite and bornite are for the most part contemporaneous in origin. They show a typical primary intergrowth, both forming irregular masses that are intimately related. (See Fig. 6.) No secondary bornite was observed, although a little secondary chalcopyrite is present. The occurrence of secondary chalcopyrite developing along cleavage lines of bornite has been described and illustrated by Graton and Murdoch.[3] Fig. 7, and Fig. 8, show this type of alteration. In Fig. 7, the gash-like structures are chalcopyrite surrounded by narrow bands of chalcocite; the main body of the slide, aside from gangue, is bornite. The thin dark line from which the gashes seem to start is a small crevice in the ore. In Fig. 8, the alteration bands narrow where they cross one another and swell out in the intervening space. The points of interest about the occurrence of this type of alteration are its limitation to contacts and to crevices in the ore, or to their immediate neighborhood, and its close association with chalcocite. The chemistry of this alteration has not been worked out.

Covellite.—Covellite is relatively widespread through the slides, where it is found accompanying chalcocite. Its usual appearance is in bunches or in feathery crystals within the chalcocite or at its contact with some other mineral. It is particularly abundant as a replacement mineral of sphalerite, its small crystals being so oriented as to conform in large part to the cleavage directions of the sphalerite. Fig. 5, shows a mass of sphalerite almost completely altered to covellite and to chalcocite. It shows also that the sphalerite is much more susceptible to alteration than is the included chalcopyrite.

Chalcocite.—All the chalcocite observed from this mine is clearly secondary, since it is found replacing all the opaque min-

[3] Graton and Murdoch, "The Sulphide Ores of Copper," *Trans. Amer. Inst. Min. Eng.*, Vol. XLV., 1914, pp. 44, 49.

erals present except magnetite. Replacement has gone on largely in the vicinity of crevices in the ore, and at the contact between ore minerals and gangue, although, in the case of sphalerite, practically the whole mass has been altered. The contact between chalcocite and the altered mineral may be sharp or it may be fuzzy, the fuzziness being due in some cases to the presence of small feathery covellite crystals. The boundary lines between masses of ore minerals appear to be important places for the development or limitation of chalcocite; for often a crevice bordered by chalcocite will stop short at a contact, and sometimes, especially in passing from chalcopyrite to bornite or to sphalerite, the band will widen out. Fig. 9, brings out these points very strikingly. Fig 10, shows the widening of a band of chalcocite on passing from chalcopyrite to bornite. It is interesting to note the unaltered grain of chalcopyrite within the chalcocite band. Under the condition of chalcocitizations of these deposits, then, it is evident that sphalerite is the most easily altered, that bornite is less so, and that chalcopyrite is the least susceptible to alteration.

The paragenesis of the opaque minerals of the Patapsco mine, then, seems to be magnetite (the oldest), carrollite, sphalerite, chalcopyrite and bornite, secondary chalcopyrite, covellite, and chalcocite. Of these magnetite, carrollite, sphalerite, and bornite are in all cases primary; chalcopyrite is largely primary, but also occurs as a secondary mineral; covellite and chalcocite are in all cases secondary. The opaque minerals are all later than the gangue, with the possible exception of a little magnetite which is earlier.

Mineral Hill Mine.

Location.—Four and one half miles southwest of Finksburg on the north side of Morgan Run, one half mile east of the state road crossing, lies the Mineral Hill mine. A rather large mine dump and a number of shallow pits show the location of the mine, which was last worked about 25 years ago.

Geology.—Geologically this occurrence of copper ore is similar to that at the Patapsco mine. The country rock to the east and

to the west consists largely of hard gray quartzose schists, which sometimes become rather micaceous, and then usually carry garnets; and sometimes very quartzose, consisting chiefly of large bands of quartz, 4 or 5 inches thick, separated by narrow micaceous stringers. These schists strike uniformly between N. 35° E. and N. 45° E., and have almost vertical dips. Pegmatite was not found with this ore as at the Patapsco mine; but just to the east of the mine the quartz schist is injected with pegmatitic material. A thin section of the country rock shows it to be similar to that of the Patapsco mine.

Here again, the material on the mine dump and from the outcrops in the immediate vicinity of the mine are seen to be of a different character from that of the country rock. Biotite, amphibole, chlorite, and talc schists comprise most of the rocks found on the dump; and chlorite and talc schists make up the actual outcrops at the mine. The biotite schists were seen under the microscope to consist almost entirely of biotite; the amphibole schists of common hornblende (altering in many cases to chlorite, talc, and epidote), zoisite, some quartz, and magnetite. A common rock noted at this mine was talc schist containing many beautiful little crystals of actinolite which under the microscope cut sharply across the plates of talc and undergo alteration to talc only at the ends or at places where a crystal had been bent and broken. This rock was not seen at the Patapsco mine, but it occurs to the south at the Springfield mine. Epidote is present in large amounts in all the slides, and appears to have been one of the latest minerals to form.

Type of Deposit.—Since the underground workings of the Mineral Hill mine are no longer accessible, it is necessary to depend on old reports for information concerning conditions underground. The ore is described as being in a vein 2 to 6 feet wide, which conformed in strike and dip with the schist. The northern end of the vein ran into the pre-Revolutionary workings, and apparently was not followed; the southern extension was cut out by talcose schist. The walls of the vein were of talcose and mica schist; the gangue was chlorite. Both copper ore and iron

ore occurred, the copper ore occupying the hanging wall side of the vein, the iron ore the foot wall side. The values were not distributed evenly, but occurred in shoots.

Description of Ore.—An examination of thin sections showed that the relations between the rock minerals and between ore and gangue is in all respects similar to the relations that exist at the Patapsco mine. The chief differences noted were the absence of pegmatite material at the Mineral Hill mine, and the greater abundance there of chlorite and talc schists. Magnetite is again present in large amounts, part of it being primary and part being introduced after the rock had formed. Bornite and chalcopyrite everywhere replace all the rock-forming minerals present with the possible exception of talc. Epidote is in most cases seen replacing hornblende and feldspar, and being replaced in turn by copper minerals. Zoisite appears to be one of the early constituents of the country rock, and probably was formed under the action of regional metamorphosing forces. Fig. 11, shows bornite replacing epidote, and surrounding quartz and feldspar.

Polished sections of ore from the Mineral Hill mine show that the ore minerals (and their relations to one another) are similar to those described from the Patapsco mine, and, consequently, little can be said other than that already stated.

Magnetite.—Magnetite is again primary and secondary (in the sense that it is later than the schist), and was the earliest of the opaque minerals to crystallize. Fig. 3, has already been used to illustrate the character of inclusions in magnetite. Fig. 12, gives a more highly magnified view of some of the inclusions. The large one near the center of the picture shows a grain of chalcopyrite with secondary magnetite within it, and within the secondary magnetite a still smaller grain of chalcopyrite.

Carrollite.—Carrollite shows roughly cubical outline, and contains some inclusions of chalcopyrite. It is apparently earlier than the chalcopyrite.

Sphalerite.—As at the Patapsco mine, sphalerite is later than

EXPLANATION OF PLATE IX.

FIG. 7. *The Patapsco Mine.* (× 365.) Polished section. This section shows the alteration of bornite (*b*) to chalcocite (*cc*) along crevices and at the contact with gangue (*G*), (feldspar) and to chalcopyrite (*cp*) along cleavage lines. (Cf. Fig. 8.)

FIG. 8. *The Patapsco Mine.* (ca. × 600.) Polished section. This section shows the alteration of bornite (*b*) to chalcopyrite (*cp*) along cleavage lines. A narrow band of chalcocite (*cc*) intervenes between the two minerals. It is interesting to note that the gash-like replacement or alteration bands become narrow where two bands cross, instead of broadening out as should be expected, if ordinary replacement were taking place.

FIG. 9. *The Patapsco Mine.* (× 87.) Polished section. Here chalcocite (*cc*) and covellite (*cv*) replace bornite (*b*), chalcopyrite (*cp*), and sphalerite (*se*). The section shows the extent to which alteration and replacement have taken place in the different minerals. The sphalerite is almost completely altered to covellite and chalcocite; bornite has altered along crevices to rather wide bands of these minerals whereas the chalcopyrite shows only slight replacement along these same lines. (Cf. Fig. 10.)

FIG. 10. *The Patapsco Mine.* (× 380.) Polished section. This shows the widening of an alteration band of chalcocite (*cc*) on passing from chalcopyrite (*cp*) to bornite (*b*). Note the unaltered bit of chalcopyrite included within the band of altered bornite.

FIG. 11. *The Mineral Hill Mine.* (× 47.) Thin section showing bornite (black) surrounding and replacing epidote (mass of slide). The light areas are plagioclase feldspar.

FIG. 12. *The Mineral Hill Mine.* (× 320.) Polished section. This is a more highly magnified picture of Fig. 3, showing inclusions of bornite (*b*) and chalcopyrite (*cp*) in magnetite (*mt*).

PLATE IX.

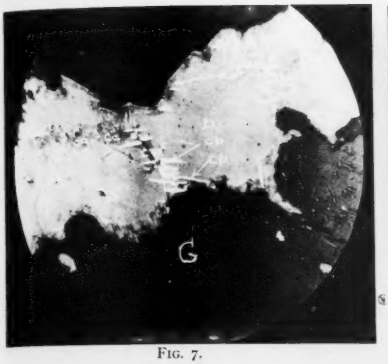


FIG. 7.

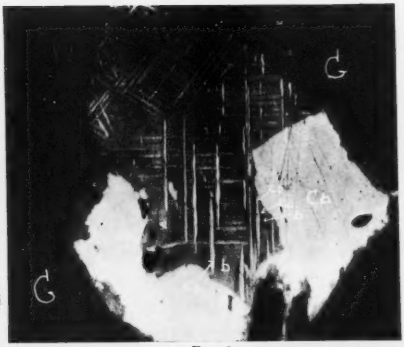


FIG. 8.

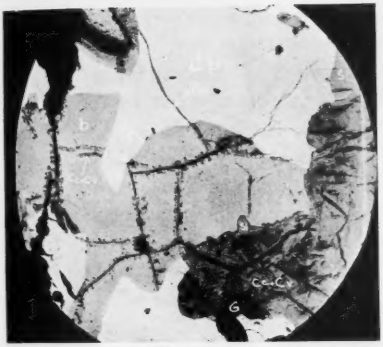


FIG. 9.

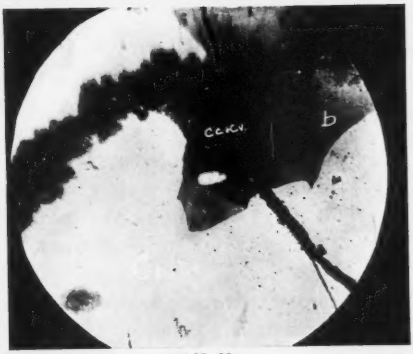


FIG. 10.

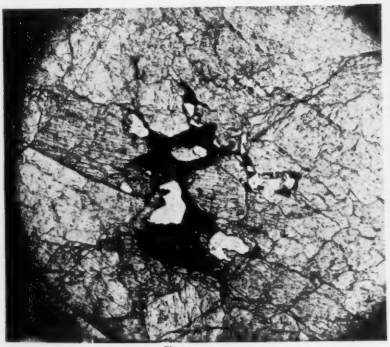


FIG. 11.

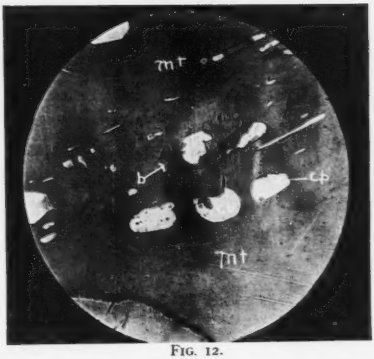


FIG. 12.

magnetite and earlier than chalcopyrite and bornite. Inclusions of chalcopyrite and bornite are exceedingly numerous, and are of two kinds: relatively large masses of the copper minerals, and small particles of chalcopyrite and bornite, which under the highest power of the microscope are seen to be definite geometrical figures—rectangles, trapezoids, and triangles predominating. Graton and Murdoch[4] call attention to the existence of inclusions of chalcopyrite possessing triangular outline, and suggest that they are probably sphenoidal crystals. Such a triangular inclusion is seen in Fig. 5. The inclusion here shown consists of a mixture of bornite and chalcopyrite, and appears not to be a crystal. Fig. 13, shows sphalerite altering to chalcocite along cleavage lines; the small white spots scattered through the slide are inclusions in the sphalerite.

Chalcopyrite and Bornite.—Chalcopyrite and bornite show typical primary intergrowth, and are contemporaneous. Both are altered to chalcocite along the numerous fractures in the ore. Fig. 14, shows the character of alteration.

Chalcocite.—Chalcocite, as has just been said, is present in rather large amount, and is always secondary. It differs from the chalcocite present in the Patapsco ore in that it does not show a fuzzy contact with the altered mineral.

Covellite was not observed.

The paragenesis of these minerals, is the same as that for the Patapsco minerals: namely, magnetite (the oldest), carrollite, sphalerite, chalcopyrite and bornite, and chalcocite.

Between the Mineral Hill mine and the Springfield mine, which lies about four and three fourths miles a little west of south of Mineral Hill, there are indications of the existence of a mineralized belt. About one-half mile south of Morgan Run on the state road there is exposed in the side of the road the weathered outcrop of a band of amphibole schist (about 150 feet wide at this point), from which a little copper was taken where prospect holes were opened in the woods southwest of this point. No more exposures can be seen until the Carroll mine, three miles to

[4] *Op. cit.*, p. 43.

EXPLANATION OF PLATE X.

FIG. 13. *The Mineral Hill Mine.* (×77.) Polished section. This section shows sphalerite (*se*) replaced by chalcocite (*cc*) along cleavage cracks. Note the numerous inclusions of chalcopyrite (*cp*) and bornite (*b*).

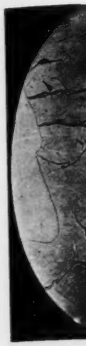
FIG. 14. *The Mineral Hill Mine.* (×60.) Polished section. Typical section showing alteration of chalcopyrite to chalcocite (*cc*) in the Mineral Hill ore.

FIG. 15. *The Liberty Mine.* (×370.) Polished section. Intergrowth of bornite (*b*) and chalcocite (*cc*). An etched section of this piece of ore shows that the fingers of bornite are parallel to the cleavage lines in the chalcocite crystal, a fact which suggests that the bornite is younger than the chalcocite, or at least contemporaneous with it.

FIG. 16. *The Liberty Mine.* (×400.) Polished section. Graphic intergrowth of bornite (*b*) and chalcocite (*cc*). The cleavage lines in the chalcocite show the relatively large size of the crystal.

FIG. 17. *The Liberty Mine.* (×320.) Polished section. Alteration of bornite to chalcocite along crevices and at the contact with gangue (*G*) (barite). Note the fuzzy contact. This is due probably to the formation of minute covellite crystals.

FIG. 18. *The New London Mine.* (×47.) Thin section of the "schistose ore." Chalcocite (black) surrounding and replacing calcite grains. Note the large crystals of calcite showing bent twinning lamellæ. The low index mineral (light) surrounded by chalcocite is quartz.



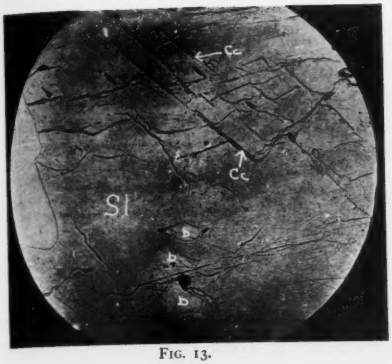


FIG. 13.

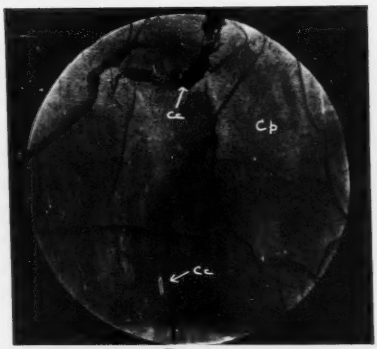


FIG. 14.

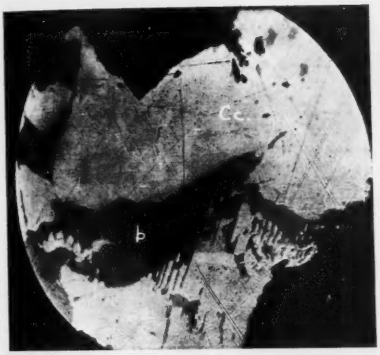


FIG. 15.

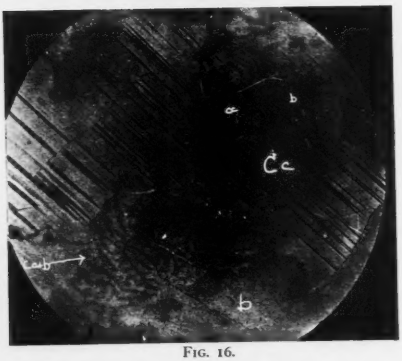


FIG. 16.

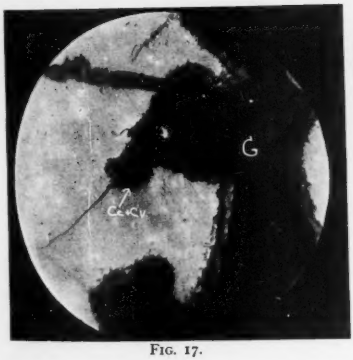


FIG. 17.

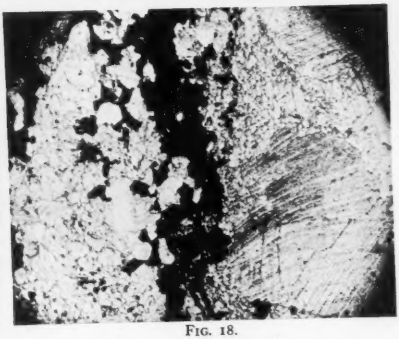


FIG. 18.

the southwest, is reached. The Carroll mine is on the north side of Piney Run about one fourth mile west of the state road, and consists of several small openings exposing a banded quartz-specularite rock. This mine was never of importance as a copper mine. One half mile a little west of south of the Carroll mine lies the Springfield deposit, one of the most important in the days of copper mining in Maryland. Since, however, this mine does not afford material for study under the metallographic microscope, a discussion of the ore occurrence will be omitted.

Genesis of the Carroll County Deposits.

Genesis.—None of the early writers who have described the eastern Carroll County deposits have discussed their genesis. The similarity of the deposits and their confinement to a narrow belt, however, were early recognized. Ansted[5] in 1854 mentions these facts, and Weed[6] in 1911 speaks of the deposits as occurring along "a copper-bearing fissure vein . . . [that] is distinctly traceable across Carroll County."

The first question to be settled, then, concerns the nature and extent of this belt in which the copper deposits are found. The following facts about it are known:

1. The copper deposits are found along a line whose strike is approximately that of the schistosity of the country rock.

2. The character of the rock found on the various mine dumps and in outcrops at the mines and in the state road south of Morgan Run, where the line was projected to cross, differs markedly from the prevailing country rock.

3. A dike of highly metamorphosed gabbro is found along a projected continuation of the line to the north of Finksburg, and can be traced for several miles.

4. Copper stains are reported from Blue Mount, sixteen miles northeast of Finksburg still on the strike of the line, and finally,

[5] Ansted, D. T., "On Some Copper Lodes near Sykesville in Maryland," *Quart. Jour. Geol. Soc.*, London, Vol. XIII., pp. 242–245, 1857.

[6] Weed, W. H., "Copper Deposits of the Appalachian States," Bull. 455, U. S. Geol. Survey, 1911, pp. 62–65.

5. Copper ores are not known anywhere in eastern Carroll County except along the line described.

It appears, then, that this is a line of structural weakness along which intrusion could take place or ore-bearing solutions travel. That such lines exist is shown by the occurrence, farther west, of a Triassic diabase dike, which can be traced practically without break across the state.

As has been pointed out above, the rocks in the vicinity of the mines are probably altered basic intrusives which were injected along this line of weakness before or during the time intense dynamo-metamorphic changes were going on. Some time after regional metamorphism ceased, pegmatitic material was injected into the country rock, and, at the Patapsco mine, into the altered intrusives. That the pegmatite is later than the schistosity is clearly shown by its relation to the schists as well as by its relatively fresh and unsqueezed condition as revealed by the microscope. After the pegmatitic injection came extensive epidotization followed by the deposition of the ore minerals.

It is proper, now, to see what evidence the minerals associated with the ore deposits have to offer concerning the conditions under which ore deposition took place. The chief rock-forming minerals present—biotite, hornblende, zoisite, and epidote—may all be the product of regional metamorphism, and hence would be expected to add nothing to a knowledge of the conditions under which the ore formed. Epidote, however, although probably part of it is due to regional metamorphism, is found replacing feldspar in the pegmatitic material, and is, therefore, later than the schistosity of the rocks. Aside from being a product of regional metamorphism, epidote, according to Emmons,[7] may be present in contact metamorphic deposits, in the weathered zone, and in deposits of the deep-vein zone. There is no evidence that these deposits are contact metamorphic deposits; and it has been shown that the epidote is earlier than the ore minerals, and gives no evidence of being due to weathering. The conclusion, then, is that the epidote is the product of the deep-vein zone.

[7] ECON. GEOL., Vol. III., 1908, p. 619.

Of the copper-bearing minerals and their accessories (sphalerite, magnetite, and spcularite), bornite, chalcopyrite, and sphalerite may occur in deposits of moderate depths, as well as in those of great depth; but magnetite and specularite are found only in veins of the deep zone.

The absence of fissure-filling and of crustification in the vein material and the presence of extensive replacement phenomena give further evidence of a deep-seated origin for these ores.

The source of the ore-bearing solutions can only be surmised, but in view of the fact that pegmatites are common throughout the region, and that large granite masses occur east and south of the belt, it seems probable that the ore-bearing solutions had their origin in a cooling granite magma. Since the granitic intrusives in Maryland are probably of two or more periods whose ages have never been determined definitely, it is impossible to say in what geologic period mineralization took place. Some of the intrusives are clearly pre-Cambrian, while others show no influence of the metamorphic action which produced the general schistosity of the region. Since rocks as young as the Ordovician are schistose, the final granitic intrusions may be Devonian or younger, and it is with these late intrusions that these ore deposits seem to be connected.

The ores, then, of the eastern Carroll County belt occur in replacement veins which were formed at great depth, and whose time of formation was after the country had undergone intense regional metamorphism. The ore-bearing solutions were ascending solutions, and probably had their origin in the granitic magma which underlay the region to the east.

The Frederick County Mines.

In the eastern part of Frederick County, about twenty miles west of the Carroll County copper belt just described, is another region in which copper mining was carried on. Two mines in this district—the Liberty mine and the New London mine—were once of considerable importance in the state as copper producers. Two other deposits—the Dolly Hyde and the New Windsor de-

posits—were considered promising when they were opened, but later work did not fulfill their early promise. One lead mine—the Mountain View Lead Mine—was opened, but was soon abandoned.

There is a marked difference in the mode of occurrence between the Frederick County ores and those of eastern Carroll County. Some of the characteristics of the Frederick County occurrences are as follows:

1. The Frederick County copper ores are scattered widely throughout the region of eastern Frederick County.

2. Many limestone outcrops occur showing copper stain, or thin stringers of copper minerals.

3. The ores are apparently confined to the vicinity of a contact between these limestones and the adjacent schists.

4. The copper ores occur as pockets or stringers in the limestones.

5. The ore minerals are bornite and chalcocite with minor amounts of chalcopyrite.

6. The gangue is calcite, quartz, and barite.

Some miles to the west of the Frederick County mines, the narrow belt of Triassic rocks that extends southward from New York cuts across the state. Traces of copper have been reported in these rocks from a number of places, but none of the deposits ever looked tempting enough to be developed. Still farther west, on the eastern side of South Mountain, copper again occurs accompanying the pre-Cambrian lava flows that form the eastern part of the mountain. No work has been done in Maryland on these deposits, although a number of mines have been opened at one time or another just north of the state line in Adams County, Pennsylvania.

Liberty Mine.

Location.—The Liberty mine is situated about five and three fourths miles southwest of Union Bridge—a town on the Western Maryland Railroad, forty-five miles northwest of Baltimore—on the Copper Mine road, one mile west of where it crosses the Liberty-Union Bridge turnpike.

A comparatively large mine dump and an old mill partly dismantled and in a complete state of decay shows the location of the mine property. Underground work has been carried on at two places on the property; one place known as the Old Workings, and the other as the New Workings. The Old Workings have completely caved, and are hence no longer accessible; the New Workings (last worked about 4 years ago) are only partly accessible.

Geology.—The Western Division of the Piedmont, in which the Frederick County deposits lie, is characterized by quartzites, schists, and limestones.[8] The quartzites are undoubtedly of sedimentary origin, consisting as they do of water-worn pebbles (varying in size from .1 inch to .3 inch in diameter). The schists are of both sedimentary and of igneous origin. The sedimentary schists are gray and sandy, or soft, dark phyllites; the igneous schists are metamorphic equivalents of acid and basic tuffs and lavas, showing very often an amygdaloidal structure. The basic rocks alter to greenstone, and seem to be more common in the southern part of the district. The limestones are found in long narrow bands in the schists; or they outcrop in small irregular patches whose geological significance is difficult to explain. Many theories concerning the structure of this portion of the Piedmont have been advanced, but none has been generally accepted.

The Liberty deposit occurs at the top of a broad flat hill, and as a consequence there are no exposures of the country rock other than those seen in the mine. A few hundred yards to the west of the mine conglomerate float was found in the field; at the mine limestone is exposed; and a few hundred yards to the east of the mine, schist occurs along the road. Here, as at most of the other localities already described, the mine dump has to be depended on to show the character of the rock in the immediate vicinity of the deposit. It is composed largely of dolomitic limestone, which is sometimes a pure carbonate, and at other times a mixture of limestone and schist. Purple, green,

[8] "The Limestones of Maryland," E. B. Mathews and J. S. Grasty, Md. Geol. Survey, Vol. VIII., pp. 350 et seq.

and gray schists are also found. The purple schist is a soft, thinly-bedded rock that shows amygdaloidal structure, and under the microscope is seen to be an altered effusive rock probably of acidic type. The soft light-green schist, apparently, is derived from the impurities in the limestone with which it is closely associated. The gray schist is amygdaloidal, and is a metamorphosed effusive similar to the purple schist just described. The limestone is a fine-grained dolomite cut by numerous stringers of coarse-grained calcite.

Description of Ore.—The copper-bearing minerals found at the mine are bornite, chalcocite, chalcopyrite, and malachite. Bornite and chalcocite are present in about equal amounts; chalcopyrite is rare; and malachite although widespread is of no importance commercially. Thin sections of the ore show the copper minerals to be the latest minerals present, since they replace the dolomite, and enter along cleavage cracks of the large calcite and barite crystals present. Quartz replaces calcite and dolomite, but is earlier than the copper minerals.

The ore minerals present in the polished sections are chalcopyrite, bornite, and chalcocite. All occur as primary minerals. Chalcopyrite and chalcocite are also secondary.

Primary[9] *Chalcocite.*—Primary chalcocite seems to have been the earliest of the ore minerals to crystallize. Etching brings out the fact that it consists of large crystals which include bornite. This bornite also seems to replace the chalcocite to some extent. Fig. 15, shows bornite with stringers arranged parallel to the cleavage lines (brought out by etching, but not shown in plate). Bornite is seen, too, in stringers between the chalcocite crystals. At times, however, the relation between bornite and chalcocite shows that they are, in some cases, probably contemporaneous; for some excellent graphic intergrowths were noted (Fig. 16).

Bornite and Chalcopyrite.—Bornite and chalcopyrite are present in typical primary intergrowths. Later chalcopyrite is pres-

[9] *Primary* is used here and below with the connotation of deposition by heated ascending solutions; *secondary*, below, of deposition by cold descending solutions.

ent to a small extent, occurring along cleavage lines of the bornite. The relations between bornite and chalcopyrite are similar to those already described under the Patapsco ores.

Secondary Chalcocite.—Secondary chalcocite is found replacing both bornite and chalcopyrite along cracks, and at contacts with the gangue minerals. This, too, has been described above. In the sections containing the primary chalcocite and the primary bornite, there is a form of chalcocite present that is of a deeper blue than the ordinary chalcocite. Graton and Murdoch[10] mention the occurrence of this mineral and make the suggestion that it is a mineral distinct from chalcocite. In the section examined, the mineral was seen in large amount intimately mixed with primary chalcocite. Its exact nature, however, could not be determined.[11]

Gangue Minerals.—Barite, calcite, and quartz occur as gangue. The barite and calcite are in well formed crystals; the quartz is in grains intimately mixed with the ore. The barite and calcite are earlier than the ore minerals, but the intimate relations between quartz and ore minerals make it appear as if some of the silica came in with the ore-bearing solutions, and was deposited as quartz at much the same time as those minerals.

New London Mine.

Location.—The New London, or Linganore, mine is about four and one half mile east of south of the Dolly Hyde mine, and about three and one half miles north of Monrovia, a station on the main line of the Baltimore and Ohio Railroad, fifty miles west of

[10] *Op. cit.*, pp. 47, 48.

[11] *Cf.* "The Sulphides of Copper," by E. Posnjak, E. T. Allen, and H. E. Merwin, ECONOMIC GEOLOGY, Vol. X., No. 6, September–October, 1915. The authors of this article call attention to the frequent occurrence of solid solutions of cupric sulphide in cuprous sulphide associated with chalcocite. These solid solutions are characterized by a blue color. The blue mineral in the section studied may be such a solution. *Cf.*, also, "Observations on Certain Types of Chalcocite and Their Characteristic Etch Patterns," by C. F. Tolman, Jr., *Bulletin of the American Institute of Mining Engineers*, February, 1916. The "blue chalcocite" is thought by Tolman to represent a transition type in the replacement of bornite by chalcocite.

Baltimore. This mine is still worked, although very spasmodically.

Geology.—The New London deposit is in the same general geologic province as the Liberty deposit. The rock types are the same, although greenstones are much more prominent in the neighborhood of the New London mine. The deposit is found in an impure limestone, which outcrops on the side of a rather steep hill. The hill is capped by a heavy quartzite, and the slopes are made up of gray schist, phyllite, greenstones, and impure limestone, all of which appear to dip to the west and hence under the quartzite. The strike of the beds near the mine is roughly a little east of north. Rock exposures are not frequent, and are difficult to interpret. At least one well-marked fault can be seen a short distance north of the mine, and there are facts that suggest other faulting. In the mine itself a fault cuts out the ore body entirely, and frequent offsetting of the vein shows still other movements.

Thin sections were made of some of the rocks found in the vicinity of the mine. The greenstone was seen to consist largely of fine-grained epidote with numerous inclusions of specularite, cut by small stringers of calcite accompanied by plagioclase. The original structure of the rocks is obscured; but its chemical composition, as revealed by the minerals present, and its similarity to rocks from the region to the west, where their nature is definitely known,[12] leave little doubt that the greenstones are altered basic effusives. A specimen of schist from the field north of the mine is seen under the microscope to be a fine-grained amygdaloidal rock showing marked flow structure. The groundmass of the rock consists of a very fine-grained aggregate of minerals which are too small to be determined with certainty, but which, on account of their general low index and double refraction, suggest quartz and feldspar. The rock corresponds closely to some of the aporhyolites from the South Mountain region described by F. Bascom. The impure limestone from the mine itself is a contorted schist with bands of limestone and soft gray phyllite. Under the microscope the bands of limestone are seen to

[12] Bascom, F., Bull. U. S. Geol. Survey, No. 136.

consist of long narrow crystals of calcite, without crystal boundary, ranged side by side with their long axes parallel; the phyllite bands are made up in large part of sericite with numerous inclusions of specularite.

Type of Deposit.—The New London deposit belongs in the same general class with the Liberty deposit, although it occurs in somewhat different form. At the Liberty mine, it will be remembered, the ore was found in stringers or bunches in rather pure limestone. At the New London mine the ore is in a fissure cutting across an impure limestone which has been mineralized. As a consequence of the impurities in the limestone, the ore is of two general types: (1) a massive ore called "typical 'vein' ore" by Butler and McCaskey[13] and (2) a schistose ore (Fig. 18). The massive ore occurs where the limestone is relatively pure, and consists of masses of chalcocite with gangue calcite and quartz in the limestone. The schistose ore occurs where the limestone consists largely of phyllite, with narrow bands of pure limestone, and represents the replacement of some of these small limestone bands by chalcocite.

Description of Ore.—The ore minerals observed in the polished sections were chalcocite and bornite. Chalcopyrite is reported from this locality by Weed, but none of it was observed. Chalcocite predominates, bornite being present only in small amounts. An etched sample of the ore shows the chalcocite to be in rather large individual crystals. In some cases it appears to be contemporaneous with the bornite, but in other cases the bornite seems to have come out of solution later than the chalcocite, since its disposition at these places seems to be entirely dependent on the previous existence of the chalcocite crystals. This condition is similar to that already described under the ores of the Liberty mine. No chalcocite that is undoubtedly secondary was seen. Although the thin sections show that some quartz is earlier than the ore minerals, the intimate relations existing between chalcocite, bornite, and quartz, as shown by the polished sections,

[13] "Copper Ores of the New London Mine," *Bull. Amer. Inst. Min. Eng.*, July, 1914.

make it very probable that some of the quartz was contemporaneous with the ore-bearing minerals.

Genesis of the Frederick County Deposits.

Genesis.—The first hypothesis as to the origin of the Frederick County copper deposits is one proposed by Weed[14] in 1911. He says:

> "The copper occurs in or alongside of masses of dolomitic limestone and marble included in micaceous schist. . . . In most of the area from New London northeastward belts of marble . . . lie east of the greenstone. The ores appear to be confined to these marbles and to the schists alongside of them, occurring either along the contact or in the fractured rock itself, as, for example, in the recent workings of the Liberty mine.
>
> "The meager facts cited would not warrant any generalizations were it not for the frequent presence of copper in the greenstone belt from Pennsylvania to the Carolinas. It is believed that this rock furnished the copper for the solutions and that the limestone and its graphitic matter supplied the precipitant for the copper."

Weed does not say whether he considers the copper to have been concentrated by cold atmospheric waters, or by warm waters, when the greenstone was first poured out as a lava and was still in a heated condition. The igneous rocks at the Liberty mine, as a matter of fact, are practically all acid intrusives similar in most respects to the aporhyolites described from the South Mountain region. Greenstones were not noted in the immediate neighborhood of the deposit.

The ore minerals, bornite and chalcopyrite, and bornite and chalcocite, are seen in the polished sections to form typical primary intergrowths as illustrated by Graton and Murdock in their excellent paper on "The Sulphide Ores of Copper."

The instability of the bornite is shown, in the sections from the Liberty mine, by its alteration to secondary chalcocite and secondary chalcopyrite. The examples of graphic intergrowth of bornite and chalcocite seem to leave no doubt as to the primary

[14] Bull. U. S. Geol. Survey, No. 455, 1911, p. 62.

nature of these ores. Emmons[15] says the following about graphic intergrowth of bornite and chalcocite:[16]

"It appears possible from these relations that under certain conditions chalcocite is deposited as a primary mineral by hot ascending waters. The intergrowth of the copper sulphide in graphic-like pattern is a feature that is difficult to explain on the hypothesis of an origin from descending sulphate waters. . . . It appears probable that under conditions where the concentration of iron is low in the solutions chalcocite may form as a primary mineral instead of chalcopyrite, which is the commoner primary ore."

The presence of calcite, quartz, and particularly barite as gangue, together with the absence of magnetite, specularite, and other high-temperature minerals, indicates (on the assumption that the ore and gangue are due to hot ascending solutions) that the deposits were formed at moderate depth.

The location of many of these deposits at contacts is probably due simply to the fact that the contact offered a path along which the solutions could move more readily, and also to the fact that the limestone furnished the agent for precipitating the copper minerals. The deposit at New London is not located at a contact, but along a fissure or a fault which cuts across a limestone band.

The derivation of these ore-bearing solutions is not certain, but it seems probable that the deposits belong to the same metallo-

[15] Bull. U. S. Geol. Survey, No. 259, p. 107.

[16] *Cf.*, however, "The Secondary Sulphide Enrichment of Copper Ores with Special Reference to Microscopic Study," by A. F. Rogers, *Min. and Scien. Press*, October 31, 1914, pp. 680–686. Rogers considers the so-called graphic intergrowths of bornite and chalcocite to be a criterion of *upward* chalcocite enrichment. *Cf.*, also, "The Origin and Occurrence of Certain Crystallographic Intergrowths," by J. Segall, ECON. GEOL., Vol. X., No. 5. Segall, referring to some so-called graphic intergrowths of bornite and chalcocite, described and illustrated in the above article, says, "it is inferred that intergrowths of sulphides may be formed by secondary processes. These intergrowths may have a close resemblance to what are known as contemporaneous intergrowths." Segall's explanation of the formation of these intergrowths would hardly apply in the case illustrated in Fig. 16, since here the chalcocite on etching develops cleavage lines in one direction only (orthorhombic cleavage), and does not show the intersecting cleavage (isometric cleavage) that seems to be the foundation upon which his argument rests.

genetic epoch as do the Carroll County ores. Both are associated areally, but not genetically, with greenstones. The type of ore-bearing solutions in both districts was apparently similar, although disposition took place under somewhat different conditions—deep-seated in Carroll County, and moderate to shallow in Frederick. Finally, mineralization in both cases is shown to have occurred after the development of schistosity—*i. e.*, in post-Ordovician times.

Thin sections of the ore show that mineralization took place after the major dynamic movements that rendered the rock schistose. It has been shown that Ordovician rocks are included in the schists of the Piedmont region: hence the date of mineralization can be put in post-Ordovician times.

SUMMARY.

Copper has been mined in Maryland from before 1760 to the present. The industry, though small in production, was of considerable importance prior to the middle of the nineteenth century, but at present it is insignificant and the production negligible.

All the commercially utilized deposits occur in the metamorphosed complex of the Piedmont, where the country rocks include metamorphosed sediments and early eruptives with later less metamorphosed eruptives. On the east, associated with the Baltimore County and eastern Carroll County deposits, deep-seated igneous masses predominate; while on the west, associated with the Frederick County deposits, metamorphosed acid and basic lavas and tuffs are abundant.

The eastern Carroll County deposits, comprising the Finksburg, the Mineral Hill, and the Springfield deposits, lie along a definite structural line of weakness that can be traced for many miles across the state. The country rock of the region is phyllite and quartz mica schist. A large granite intrusive lies near the southern end of the copper belt, and pegmatite dikes are common throughout the region. Altered basic intrusives are found along the line of weakness, and it is with these that the

copper ores are really associated. The ore occurs in replacement veins roughly conformable in strike and dip with the country rock. The ore minerals are chalcopyrite, bornite, carrollite, chalcocite, and covellite, and associated with these are sphalerite, magnetite, and specularite. Chalcopyrite, bornite, sphalerite, magnetite, and specularite form primary intergrowths; chalcocite and covellite are always secondary, replacing all the minerals present except magnetite and specularite. The gangue minerals present are hornblende, biotite, epidote, and feldspar, all of which are partly replaced by the ore minerals. The paragenesis of the ore minerals and associated minerals is magnetite, hornblende, biotite, epidote, quartz, feldspar, magnetite, carrollite, sphalerite, chalcopyrite and bornite, secondary chalcopyrite, covellite, chalcocite—magnetite being the oldest.

The varieties and relationships of these minerals present in the deposits indicate that deposition took place from hot ascending solutions, and at considerable depth. Secondary alteration to chalcocite due to descending solutions has taken place along crevices in the ore, but is of little importance. Deposition was shown to have taken place after the period of metamorphism of the region, probably in post-Ordovician time. That the source of the ore-bearing solution was probably the granitic magma from which the pegmatitic material came, is indicated by the presence of a large granitic mass near the copper belt, and by the general agreement in age of the ore deposition and the intrusion of the granite.

The Frederick County deposits, comprising the Liberty and the New London deposits, are confined to limestones at or near their contact with other rocks. The country rock of the region consists of metamorphosed sedimentary rocks, and altered acid and basic extrusives. The ores occur as pockets and stringers in limestone, or as replacements of calcareous bands in impure limestone. The ore minerals are chalcopyrite, bornite, chalcocite. Quartz, calcite, and barite form the gangue minerals. Chalcopyrite and bornite show primary relationships; bornite and chalcocite occur in graphic intergrowths, and are in part prob-

ably contemporaneous in origin. Secondary alteration to chalcocite is prevalent, but is not important. The paragenesis of the minerals (in the order of deposition) would be calcite (?), barite (?), quartz, chalcocite, chalcopyrite and bornite, secondary chalcopyrite, secondary chalcocite. Some quartz is probably contemporaneous with the deposition of the ore minerals.

The character of the minerals and their associations thus point to deposition from hot ascending waters at moderate depth. Mineralization apparently took place after the metamorphism of the region. The source of the ore-bearing solutions is not certain, but it seems probable that the mineralization was contemporaneous with that in Carroll County, and that the ore-bearing solutions probably have a common source. There is no evidence that the solutions were derived from the greenstones of the region with which the deposits are frequently associated.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE ORIGIN AND OCCURRENCE OF CERTAIN CRYSTALLOGRAPHIC INTERGROWTHS.

DISCUSSION OF PAPER BY JULIUS SEGALL.

Sir: I have read with interest Mr. Julius Segall's paper "The Origin and Occurrence of Certain Crystallographic Intergrowths" in the July–August issue of the past year.

A large part of Mr. Segall's article is taken up with a discussion of microphotographs illustrating the association of bornite and chalcocite as they occur in the Leonard Mine, Butte, Mont. As I have also studied these ores I may perhaps be permitted to take issue with some of the author's conclusions regarding these relations.

My discussion will be concerned principally with the bornite-chalcocite relations which Mr. Segall describes in connection with the microphotographs (Plate XIII., Figs. 1, 2, 3, 4, 5, 6, and Plate XIV., Fig. 7) of his article. The specimens which Mr. Segall studied from the 1,845- and 2,200-foot levels of the Leonard mine came from a part of the district in which bornite occurs much more sparingly than at many points a little more distant from the central part of the copper area; in other words, bornite occurs more abundantly as we approach the "intermediate zone" of Sales.[1] In the Leonard mine, especially near the shaft, and

[1] Sales, Reno, "Ore Deposits at Butte, Mont.," A. I. M. S., Vol. XLVI.

EXPLANATION OF PLATE XI.

FIG. 1. Tramway Mine, Butte, Mont., 2,200-ft. level. Mag. = 93 diams. Chalcocite (*cc*) replacing bornite (*Bo*). In the chalcocite is seen a typical structure left by a partial replacement of bornite.

FIG. 2. Tramway Mine, Butte, Mont., 2,200-ft. level. Mag. = 800 diams. An enlargement of part of the field just off the lower right hand corner of Fig. 1. Bornite (*Bo*) is parted along crystallographic planes, possibly inherited from enargite. Chalcocite is later than the bornite, the attack of the chalcocite forming solutions being along the crystallographic or parting planes.

FIG. 3. Tramway Mine, Butte, Mont., 1,600-ft. level. Mag. = 800 diams. Bornite (*Bo*) is replaced by chalcocite (*cc*), forming the typical structure sometimes seen in bornite-chalcocite and sometimes the replacement has been more nearly complete and the same structure is developed in blue and white chalcocite.

FIG. 4. Tramway Mine, Butte, Mont., 1,600-ft. level. Mag. = 800 diams. Showing development of blue chalcocite (*b.cc.*) in white chalcocite (*cc.*) as the result of almost complete replacement of bornite by chalcocite.

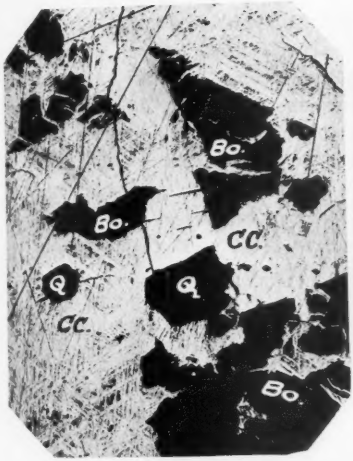


FIG. 1.

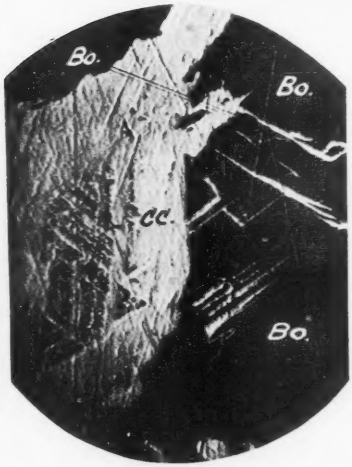


FIG. 2.

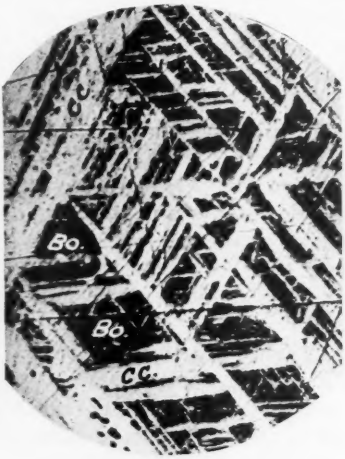


FIG. 3.

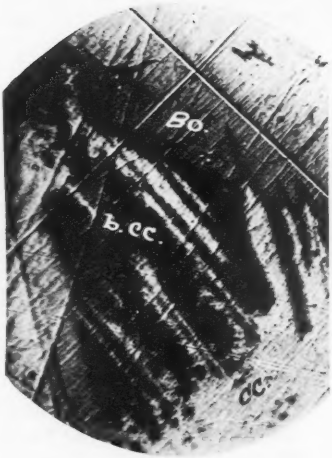


FIG. 4.

points to the westward, the mode of occurrence of the particular type of bornite which Mr. Segall describes is very obscure, because replacement by later minerals has been carried on to an advanced stage, and the true relations of bornite of this type and chalcocite are not easily deciphered. As we pass from the Leonard shaft towards the east and southeast bornite appears in greater abundance, and in the Tramway mine, lying a few hundred yards to the southeast of the Leonard, bornite is found undergoing all stages of replacement by chalcocite. Had Mr. Segall had an opportunity to study a complete set of specimens illustrating the point under discussion I feel sure he would have arrived at very much the same conclusions as myself. Without a study of the broader genetic and structural relations as obtained in the field the microscopic study of polished sections of ore is often apt to lead one astray.

On page 465 Mr. Segall describes a process of replacement of chalcocite by bornite, the replacing solutions circulating along tiny fractures as illustrated in Figs. 2, 3 and 4, Plate XIII. of his article. I firmly believe these fractures to be post-mineral and here introduce a series of my own microphotographs to prove the point. Fig. 1, Pl. XI., shows the broader relations of bornite and chalcocite as they occur in a specimen collected by myself from the 2,200-foot level of the Tramway mine. The hand specimen from which this section was cut (Bu. No. 226; 2208 sill, "Tramway") is very interesting both megascopically and microscopically. The ore megascopically presents the structural appearance of enargite, but the mineral is principally chalcocite. It breaks along cleavage planes similar to those of enargite and contains the same pyritic inclusions as massive enargite collected from the same mine. The specimen presents a splendid example of almost complete metasomatic replacement of coarsely crystalline enargite.

Microscopically the ore is seen to contain much bornite, as illustrated by Fig. 1, Plate XI. Post-mineral fractures break through the ore cutting bornite and chalcocite irrespectively. A study of many specimens of the same type of ore fails to reveal any close relation between this particular occurrence of bornite

and fractures. The chalcocite in Fig. 1 exhibits the same structure as that illustrated by Mr. Segall in Plate XII., Fig. 1 of his article. Under higher magnification the checkered structure can be found to grade in all proportions of bornite and chalcocite from solid bornite to nearly pure chalcocite. The general appearance seems to indicate a breakdown of bornite and replacement by chalcocite. Fig. 2 is an enlargement of a part of the field just to the southeast of the bornite shown in the lower right hand corner of Fig. 1. The same fracturing of the bornite along crystallographic or cleavage planes is here very clearly brought out. The structural lines of the checkered design of bornite-chalcocite in the left half of the photograph are seen to check very closely with the parting lines in the massive bornite. It is an observed fact that etch figures obtained from chalcocite do not show continuity of direction over comparatively large areas such as are generally found in the type of structure here under discussion. That the chalcocite in the fractures of the bornite on the right of Fig. 2 is later than the bornite itself requires no discussion. It would hardly be possible for replacement to take place so regularly as to leave the sharp contacts and narrow, clearly defined bands of chalcocite if bornite were the replacing mineral.

Fig. 3 shows the halfway stage in the replacement of bornite by chalcocite. Fig. 6, Plate XII., shows the development of so-called graphic structure entirely within the undoubted replacement structure. Figs. 3 and 6 were taken after the specimen was freshly polished and before any of the "blue chalcocite" had time to develop by tarnishing. Fig. 4 illustrates the development of this blue chalcocite which results from an incomplete replacement of bornite by chalcocite. It is seen that the white stripes parallel or run into the partings in the bornite. Where the replacement is incomplete as in the narrow partings along the border of bornite and chalcocite the mineralizing solutions did not have sufficient time to entirely eliminate the iron from the bornite and part of it was probably left as an impurity in the chalcocite. In these specimens no blue chalcocite was visible directly after polishing, but during the ten or fifteen minutes occupied in taking the photographs shown in Figs. 3 and 6 the

blue chalcocite developed as shown in Fig. 4. Often the structure developed by blue chalcocite is identical with that shown in Fig. 3. It then seems that the white stripes developed in this design are merely the channels through which the replacing solutions passed for the longest time and, where the process of replacement is suspended before completion, we find the design as here illustrated.

To what mineral these designs, or rather directions of parting, may be ascribed is somewhat of a problem. Enargite has parting in three directions and may very well have induced this parting on the bornite which replaced it and was in turn replaced by chalcocite. I have noticed in the case of Butte that this type of structure in the blue and white chalcocite or in bornite and chalcocite only occurs in those parts of the district where enargite occurs as an earlier mineral. In the specimens discussed here enargite occurs quite abundantly in microscopic remnants and I have already spoken of the enargite structure exhibited by the hand specimen.

A somewhat different structure is sometimes exhibited in bornite which replaces sphalerite. Fig. 5, Plate XII., shows bornite which has replaced sphalerite, the structural lines here shown in the bornite are continuous into a residual particle of sphalerite. The contact of sphalerite and bornite was not shown in this photograph as I wished to illustrate the deposition of chalcocite along these inherited parting planes. Where chalcocite has replaced the bornite to a greater degree a most beautiful "graphic" structure is developed and the two minerals take on the typical appearance of the "graphic intergrowth" of Laney (not shown in Fig. 5).

Other types of replacement which I have observed at Butte and which take on the appearance of graphic intergrowths are, tennantite and bornite (Fig. 7), galena and bornite (Fig. 8), klaprothite and bornite, tetrahedrite and chalcopyrite, tetrahedrite and bornite, and galena and argentite.

In conclusion then, I agree with Mr. Segall that the bornite-chalcocite structure discussed and illustrated by him from the Leonard mine is not a "graphic" intergrowth, but I most de-

EXPLANATION OF PLATE XII.

FIG. 5. Colorado Mine, Butte, Mont., 1,400-ft. level. Mag. = 93 diams. Bornite (*Bo*) which has replaced sphalerite and still retains the cleavage planes of the earlier mineral. Chalcocite (*cc.*) has later come in along these inherited cleavage planes and replaced the bornite. Where this replacement by chalcocite is carried further along the resulting structure simulates the beautiful "graphic" intergrowths often seen in alloys.

FIG. 6. Tramway Mine, Butte, Mont., 1,600-ft. level. Mag. = 800 diams. Another part of the same specimen shown in Figs. 3 and 4, illustrating the development of so-called graphic intergrowth in the midst of undoubted replacement structure. Light, chalcocite; dark, bornite.

FIG. 7. Speculator Mine, Butte, Mont., 2,000-ft. level. Mag. = 800 diams. Tennantite (*T*), chalcocite (*cc*) and bornite (*Bo*) in so-called graphic intergrowth. The negative was retouched to bring out more contrast between the chalcocite and tennantite.

FIG. 8. Gagnon-Original Mine, Butte, Mont., 2,800-ft. level. Mag. = 260 diams. Galena (*Ga*) and bornite (*Bo*) simulating graphic intergrowths. The galena belongs to an earlier sphalerite-galena period of mineralization which was in turn partially replaced by enargite (*Eng*). Later bornite replaced part of the remaining galena.

FIG. 5.

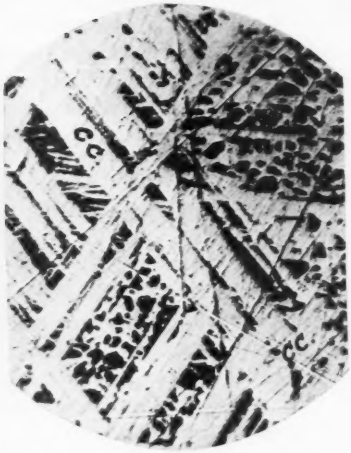


FIG. 6.

FIG. 7.

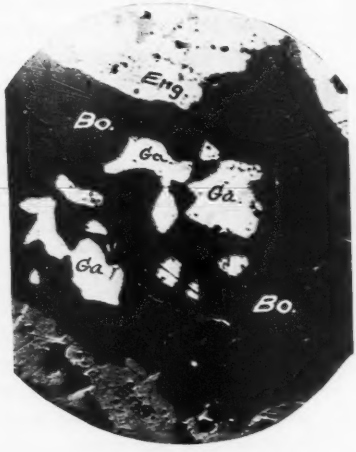


FIG. 8.

cidedly do not agree with him as to the sequence of the two minerals. I believe that the type of bornite here under discussion is earlier than the chalcocite and has been partially replaced by the latter mineral giving the structural designs as illustrated by Mr. Segall and by myself in this discussion.

JAMES C. RAY.

Sir: You ask, "Would it be advisable for universities to grant the degree of 'mining geologist.'"

I presume that you recognize a distinction between the terms "economic geologist" and "mining geologist." If a mining geologist is a geologist who applies his knowledge of geology to the investigation of ore deposits, who makes of his geology a profession from which he earns a livelihood, he is, to my thinking, an "economic geologist," rather than a "mining geologist."

The term "economic geologist" has always appealed to me as being the proper term in which to express the application of a thorough knowledge of geological phenomena to the everyday business of the development of a mine. The application of the laws governing the deposition of the minerals and metals in the earth's surface, in rocks, in veins or deposits, has brought to the attention of the practical miner the value of a thorough training and knowledge of these laws as applied to the development of ore deposits. Indeed, the advance made in this direction of late years by geologists has been phenomenal.

The study of "secondary enrichment" and its exposition by the geologists of the world, has enriched the literature of geology and materially added to the world's knowledge of this important subject.

The practical application of the theory of "secondary enrichment" has been most productive in results as evidenced, for instance, in the advance made in the development of many deposits where this theory has been worked out to a successful conclusion.

The economic geologist has earned for himself a well deserved position in the field of mine development. He is becoming more and more necessary to the everday business of developing mining property. No efficient mine manager can, as a matter of

fact, neglect to recognize the value of his services. His the duty of replacing, the "divining rod"; the rule of thumb of the mine foreman (to whom, unfortunately, this important work has been left in many cases); in saving the foolish expenditure of money, in useless driving of tunnels, and drifts, and of sinking costly shafts, in a vain attempt to fathom nature's secrets by force of drill and powder with no knowledge of the fundamental laws laid down by geologists. The intricate vein systems produced by faulting, the effect of intrusive dykes on these systems, the complicated and puzzling ore occurrences which baffle the practical miner, are far less difficult problems to the experienced economic geologist.

There seems, therefore, no question as to the place in the economy of mining which the geologist has earned for himself. He is no longer a luxury, he is a necessity, no longer a theorist, but practical, no longer a scientist teaching a dry subject, but one who deals with the realities of ore occurrence to add to the wealth of the world.

A geologist need not be a mining engineer, need not be a practical miner. This makes the term "mining geologist" a bit out of tune. The only interest which a geologist has in underground workings is to have them in such shape that he won't break his back in going through them in the study of the rocks.

I am in favor of granting a degree which will adequately express the profession of "economic geologist" and give him the niche in the academic world which he has earned for himself.

BENJAMIN B. LAWRENCE.

60 WALL ST., NEW YORK.

Sir: My own experience of mining geology is largely confined to metal mining. With that limitation my opinion would be that university training for a mining geologist should follow much the same lines as for a mining engineer, the principal subjects being, ability to use the English language correctly; physics with mathematics; chemistry; mineralogy and petrography; geology; surveying and sampling.

A mine manager needs to take mechanical engineering, which

a metallurgical engineer needs to be taught on somewhat different lines. In many ways the mining engineer proper is nearer to the geologist than he is to the metallurgical engineer, and I cannot agree with Professor Haworth that a geologist does not need to be an engineer. The geologist may not be called upon to do much actual construction, which comprises most of the work of many mining engineers; but he must be a first-class surveyor, and he needs to be able to understand nature's processes. To assist him to attain the latter object the mathematical training given in most engineering colleges should be of great value.

A degree in geology, which preferably should be either *bachelor of geology* or *doctor of geology,* should assist the universities in arranging courses for geologists who would afterwards enter government service, devote themselves to teaching, or engage in private mining practice, and to that extent would be of definite service.

But the few years that a young man spends at a university cannot insure his success in any calling followed by him in after life. Membership in a good professional society is of much more financial value to a professional man than university degrees, for it shows that he is still interested in his subject, and that through devoting themselves to the study or practice of the same subject receive, and associate with, him on terms of equality.

The Geological Society of America is composed of geologists whose qualifications have been examined and acknowledged by the council and the other members, and the Mining and Metallurgical Society of America, after careful scrutiny, admits geologists to its membership.

With these two great societies to serve as guarantors for a mans' qualifications the reputable mining geologists of America could soon eliminate the charlatans if they would refuse to recognize as associates men calling themselves geologists who were not members of one or other of these two societies.

J. B. TYRRELL.

Sir: I have already advocated the idea of establishing a title for mining geologists in some of our universities, in lectures,

which I gave at the University of Chicago, and am most heartily in favor of the idea. I am not so sure that the degree should be "mining geologist," although that is a dignified and expressive title. I have had some preference for the title "geological engineer," largely for the reason that a geologist, to be of greatest service in mining, should supplement his geological training with a sound knowledge of at least the rudiments of civil and mechanical engineering—*i. e.*, those phases of the two subjects which are almost constantly in use in mine operation. As a matter of fact, mine operators, when they employ a geologist, appear to take it for granted that, if he represents himself to be a mining geologist, he really does possess the training of an engineer.

JOHN W. FINCH.

Sir: I should think that it might be a very good idea to create the degree of "mining geologist," although possibly some other title with the same significance might be suggested that would sound a little better and have a slightly wider scope. For instance, a geologist equipped to advise on oil lands is hardly a mining geologist. The title might be "graduated in economic geology."

In my opinion such a profession can never be anything except a highly specialized one, and a degree in it should be a graduated degree, higher than that of mining engineer.

It would be unfair, however, to raise any prejudice against mining engineers, specialized in geology, on calling themselves "mining geologists" after considerable experience has been gained by them in the geological side of mining. This often happens. A knowledge of how to do geological work often turns out to be the most valuable equipment for a mining engineer.

J. R. FINLAY.

Sir: In regard to the granting of the degree of mining geologist by universities it is certainly true that the term is used very extensively by entirely incompetent men. The only question in my mind is whether, in view of its present use, the title should be adopted by the universities, as such action might have the effect

of strengthening the hands of those using it at present, giving the impression that they had the authority to do so. I always think of the case of an acquaintance who was chief engineer of a corporation and always signed C.E. after his name, on my protesting he stated that C.E. to his mind meant chief engineer, and that he did not know any law which would prevent his using the abbreviation if he was so disposed, and he did use it up to the time of his death.

R. V. NORRIS.

Sir: I have read with a great deal of interest the communication advocating the granting of a degree of mining geologist, by the universities of the United States. I imagine that my opinions on the subject will not be similar to those held by the majority of your correspondents.

In the first place I cannot see that the granting of a degree of mining geologist by any of the universities would tend to check the practice of other men calling themselves mining geologists, or other similar terms. We have, at the present time, a large body of well trained geologists who would, undoubtedly, be entitled to use this title, even though they had never received a degree from a university and I believe that there has been a general consensus of opinion that a man who was actually engaged in any occupation had the right to so classify himself, leaving it to the public and his clients to judge whether or not he really possessed the attainments which such classification implied.

I recollect some years ago, when the question was raised as to whether or not a man, who had not received a degree, had the right to assume the title of mining engineer,—that some of the best posted engineers of the country expressed their strong conviction of any man who was actually engaged in mining engineering had a right to call himself a mining engineer; and we all know that many of the most skillful mining engineers have received degrees as bachelors of science, mechanical engineer, or civil engineer, or even as bachelors of art,—and in some cases no degree at all. These men have, however, learned the profession by actually following up the work in the field and at the same time

reading and studying the literature pertaining thereto and the same may be said of mining geologists, at the present time. To me, personally, it would seem that geology would be one of the most difficult studies to learn thoroughly in a university and, unless at least two or three years of active field work in connection with a geological survey or mining operation were made a part of the requirements for the degree of mining geologist, I cannot see that this degree would mean anything very important, or would tend to qualify its holder for any geological work of real responsibility.

Another point which occurs to me in this connection, is whether the demand for mining geologists justifies special courses at the universities towards the granting of such a degree. We all know that the geological survey of the United States and several of the states, employ a certain number of geologists and generally speaking they engage young men to hold the minor positions and these men become proficient by many years of practical experience before they attain the more responsible positions. They do not, as a rule, require any special training for the minor positions in connection with the geological survey, these positions being held by young graduates from the mining schools, or various scientific schools throughout the country.

The larger mining companies frequently employ mining geologists whose work is very important and highly special, but as far as I have been able to gather they, naturally, always choose for these positions, men who have attained a considerable reputation by their work for the government or one of the states, and I doubt very much if any young graduate mining geologist could hope to secure any better position with these companies than can be sesured to-day by the graduate mining engineer.

The smaller mining companies generally get along without the services of any geologist at all, or have their mine superintendent or mining engineers do such geological work as is necessary and I can hardly imagine that there would be any very wide field for the services of these proposed mining geologists, outside of state and government work and a few of the larger companies, as men-

tioned above, and unless the holders of these degrees were prepared to accept the positions which are ordinarily open to young engineers; as surveyors, assayers, samplers or assistants in particular phases of underground work, it seems to me that they would find considerable difficulty in obtaining employment.

Taken altogether, my opinion is that the need for mining geologists is not sufficiently great, at the present time, to make it worth while for the universities to have special courses, looking towards the granting of such a degree, nor to grant the degree in question, but I would suggest that for those students who desire to specialize in geology, post-graduate courses might be provided and special attention paid to geological work. It would then be possible, for instance, to grant the doctor of philosophy degree to any young man who had specialized in geological courses and to let it be understood that the Ph.D. had been given to him for his *proficiency in geology* and for actual field work of value in this science, as well as class-room work and thesis.

I note that your correspondent states that in the middle west, many men want the degree of mining geologist. My own experience has been more particularly in the East and Far West and I have not come across many men who expressed this desire. I have had a great many young engineers come around and say that they intended to specialize in geological work and were looking for an opportunity to get special employment which would give them an opportunity for experience in this line, but generally speaking these young men have had to content themselves with some other field of endeavor, because from a practical standpoint it does not pay the mining companies to employ geologists, except for the working out of particular problems or possibly to assist them in litigation, and for such work only men of wide experience and reputation are in demand.

No doubt conditions are gradually changing and the value of geologists is being realized more widely than ever before. I consider that any man who desires to conduct mining operations intelligently, should have a good ground work in the science of geology and should be able to work out for himself or for his

company, the simpler problems which he will meet in the course of his daily operations, but when it comes to the more complicated geological problems, or the complete geological survey of mining districts, I feel that this work can safely be left to the very large mining companies, or to the government and as long as the majority of the smaller concerns feel this way, I think that the field for graduate geologists will always remain limited and personally I am rather skeptical as to the success that would attend the efforts of any university to grant a degree of "mining geologist."

G. M. COLVOCORESSES.

Sir: The title of "mining geologist" is, in my judgment, desirable, since it implies that association of engineering and more purely scientific studies and experience which a man, who wishes to follow the profession of an expert in mining, should have. The title is of practical value in the profession because it associates applied science with an understanding of the underlying principles. Furthermore, it is a title which contrasts favorably with that of "engineer" inasmuch as it does not suggest the mere mechanical aspects of engineering to which the professional mining engineer is too often restricted.

While thus approving the general title of "mining geologist" for business purposes, I do not think it desirable to introduce it into the university as a degree which shall stand somewhere between that of A.B. and A.M. There is a distinction between a business title and a scholarly degree. The one may be used in business to define the activities to which the individual applies himself and is subject to such conditions as he may judge to be appropriate. The other is the stamp of a certain scholarship and learning obtained by the holder as determined by a qualified faculty. The former may be indefinitely specialized as is the case in the practice of medicine. The latter may be wisely broad in its significance since it stands for a certain degree of culture rather than for special attainment or proficiency.

As regards the argument suggested by some writers that the degree of "mining geologist" should be given because charlatans use the title, I fail to find it convincing. If the degree already

lacks dignity, we shall hardly give it that desirable quality by sharing it with those who have found it commercially profitable.

Furthermore, so far as Stanford University is concerned, we are bound by a joint action of the faculty which has determined that we should give the degrees of A.B. and A.M. without distinction as to the particular branch of study in which the student has qualified, and we are not at liberty to act independently in the matter.

BAILEY WILLIS.

Sir: My first impulse is to say No! such a degree is won by years of study and work out of college, and no university course is long enough and varied enough in its teaching to justify the granting of such a degree. But, the thought instantly arises that such is the case with any degree. Consider LL.D.'s and Ph.D.'s or M.D.'s. How many men who bear these degrees are really masters or "doctors" of their special subject when the degree is conferred? The physician goes out and "practices" on his patients, and if he practice diligently and continue to learn, some time in a long career he may be considered really worthy of his degree. And after all, if it be only a bachelor's degree at the outset, and the master's degree come later, why not?

We all know that there is no degree which at present conveys the idea of proficiency and special fitness along the line of an understanding of the valuable elements of our rocks and soils. Geology has as many branches today as natural science possessed in the days of our grandfathers. Mining engineers may, and commonly do, have difficulty in distinguishing between the ordinary varieties of rocks, and be hopelessly at sea when requested to make a geological map of a bit of complicated underground mine development. How, then, shall be credited to a man special interest in, and preparation for, mining geological problems and investigations?

On the whole, if granted under proper restrictions, and held up to a high standard, I think such a degree may prove to be proper and useful.

HORACE V. WINCHELL.

REVIEWS

A Textbook of Geology: Part I., **Physical Geology,** by LOUIS V. PIRSSON. Part II., **Historical Geology,** by CHARLES SCHUCHERT. In one volume, 1051 pages; 6×9; 522 text figures, and 40 plates; appendix, index, and folding colored geological map of North America. Cloth $4.00 net. John Wiley and Sons, Inc., New York, 1915.

This volume is the latest of the series of noteworthy texts that at varying intervals have emanated from the group of active and brilliant workers in geology and kindred subjects at Yale University. It is appropriate that it should be dedicated to the late Prof. James Dwight Dana, whose influence as a teacher and writer so shaped the thought of American geologists of the past generation. The two parts of the book, though supplementary, are really separate texts. There are cross references between them, however, and they are readily adaptable for use as the basis either of a single full year (college) course or of two half-year courses. As might be expected, the volume reflects the high standards of work of its distinguished authors. The selected point of view is that of the college student's first course in geology and many details and technicalities are therefore omitted. The presentation of the subject is, however, sufficiently mature to interest the more advanced student and the well-informed general reader.

In the preface to Part I. Professor Pirsson calls attention to the tendency of recent textbooks to over-emphasize the physiographic aspects of geology and expresses his aim to present a more evenly balanced treatment of the subject. In this he appears to have succeeded admirably as is fairly well shown in the amount of space devoted to the different chapters, which number 16 and occupy 403 pages.

Physical geology is treated in two divisions, namely, dynamical geology and structural geology. The broader subjects described under the above heads are more or less traditional but the selection of the important material from the wealth of details now available is a somewhat difficult matter and the author has made a happy choice. The condensation necessary in a book of this character involves dangers which are almost impossible to avoid since by the omission of details and the abbreviation of statement misleading or erroneous impressions may be conveyed to the reader. There are, too, expressions more or less er-

roneous which have become current through textbook and other usage and are difficult to eliminate. A few examples of such defects in the present text, which may be improved in subsequent editions and do not seriously detract from the general excellence of the book, may be given here.

Page 88. Waves. "When the circle [orbit of water particle] intersects some obstacle, such as the bottom, when the wave form moves into shallow water, the lower part is retarded, the top rushes forward over it, and this water is given a strong forward motion." This is the retention of a statement that has been current in many texts but has been shown to be erroneous by Davis and by Fenneman.

Page 170. Iron-ore deposits. The association of the Clinton iron ore with the discussion of the changes from ferrous carbonate to limonite is misleading. The origin of the Clinton deposits has been the subject of considerable discussion, and it is probable that the processes of its formation were much more complex than those outlined.

Page 211. "The fact that most volcanoes are situated in, or near, the sea or lakes has been considered a strong proof that the water-gas contained in the magma has been obtained from descending surface waters." *Water-gas* usually has a different connotation from that here given.

Page 223. "Raised strand-lines prove that within a recent geological period the west coast of South America has been elevated in places over a thousand feet, and the process is probably still going on." Suess long ago pointed out, and more recently Woodworth has shown, for southern Chile at least, that Darwin was mistaken in ascribing to that coast changes of level as great as 1,000 feet.

Page 256. "A collection of beds, lying concordantly above one another and deposited during a given geological period of time, is called a formation." A formation is here inadvertently made by implication the equivalent of a system.

Pages 373–374. "The Jura Mountains of Switzerland . . . present a type of very youthful dissection; here the structure forms produced by folding still give the dominant topographic features, which erosion has, as yet, been unable to essentially modify. Ranges like . . . many of the Rocky Mountains' system, are still in a youthful stage of dissection, although their topographic relief, that is their mountain forms and valleys, is dominantly one of erosion, and not evidently of folding, as the Jura." This statement is misleading, for in both the Jura and the Rocky Mountains the present forms represent the later phases of a long and complicated history including more than one erosion cycle.

In the opinion of the reviewer the chapter on ore deposits might better have been entitled, Economic Deposits, and enlarged in scope to

include, with some supplementary matter, the discussions of those subjects in Part II., which there more or less interrupt the continuity of the geologic narrative.

Appendix *A* is an extension of Part I. and includes the names, with brief descriptions, of certain minerals that are geologically important in rocks and ores.

In the preface of Part II., Professor Schuchert explains the need he found of showing to students the relationship of historical geology to astronomy and evolution, biology and oceanography, and of including in his teaching some discussion of the living world. He has accordingly devoted to these subjects some 10 chapters or about 130 pages. This well selected material forms an admirable setting for the discussion of the geologic record that follows.

Professor Barrell contributes Chapter XXV. on the origin of the solar system under the planetesimal hypothesis, besides a number of shorter sections. Professor Lull supplies Chapter XLVI. on the dinosaurs and is credited with aid in 9 other chapters. Dr. E. O. Ulrich presents a statement on the Ozarkian period.

In addition to the introductory pages there are 10 chapters of a more or less biological character, and a chapter on coal, besides smaller sections on economic deposits interspersed with the discussion of the geologic periods. These chapters are excellent and of great interest for the student but in the opinion of the reviewer a greater degree of continuity of subject would be gained by grouping much of the economic data with the chapter on ore deposits as above suggested, and much of the biologic data with the chapter on matter and organisms. Progression by digression may not, however, be without its advantages in presenting a subject which many beginners have found rather dry.

The geologic story is told in a very interesting way and with as great a reduction as possible of paleontologic detail. This has doubtless been done to relieve the student of technicalities but it may be questioned if the curtailment in this direction has not been too great. As might be expected from the well-known labors of the author, much emphasis has been placed on the paleogeographic aspects of the record, and this has added to the interest of the volume. The latter is distinctly a North American textbook but the geology of other continents receives some attention, particularly in its relations to faunal and floral distribution.

In spite of the reiteration of the principle of the permanency of the continents and ocean basins, much reliance is placed on the existence and influence of hypothetical continents, such as Eria, Gondwana, and Lemuria. A more conservative stand in this matter might perhaps be more appropriate in a book for beginners in geology.

A feature which will cause much comment among geologists is the time scale tabulated on pages 442–445 and its application in subsequent pages. The explanations in Chapter XX. do not give sufficient background for so complete adoption of the so-called *new periods* as is implied in the text. As the student reads the succeeding chapters he gains little inkling that some of these periods have long been known by other names, or that others are regarded by many geologists as hypothetical or without justification.

On page 539 the work of the International Committee of 1905 and the Twelfth International Geological Congress of 1913 are both mentioned, but the student is given little idea of the great differences of opinion with regard to pre-Cambrian correlation brought out at the latter gathering. The table on pages 444–445 does not give the pre-Cambrian time divisions as agreed upon by the International Committee, or as generally employed by the United States Geological Survey. Instead, a modified table, prepared by Professor Barrell and based largely on the work of the Canadian geologists, is presented. This would be admirable, if the other classifications were also given for comparison. In the descriptions of the pre-Cambrian periods the author follows in the main the views of Professors Coleman, Lawson, and others who have worked chiefly north of Lake Superior. No idea is given in the text of the long-standing difference of opinion between the above-named geologists and those who have worked chiefly south of Lake Superior, where conditions are very different, regarding the relative importance to be attached to certain criteria of correlation and to the resulting time divisions. The correlation adopted fits well in the diastrophic scheme which the author has selected as the basis of his discussion of historical geology, but, to present only one side of a controversy, however satisfactory and plausible it may appear, is unfair to the student and such presentation in a textbook should be avoided.

In the discussion of the Cambrian two series names are employed which are generally new to textbooks, although one of them in its original form has been so used before. These are the terms Waucobian and Croixian. There is no suggestion that these series have long been known by other names. This again is unfair to the student who should at least be given the older names in parenthesis if space does not permit explanation of the change. Incidentally, there seems no valid reason for modifying Walcott's term St. Croixan to Croixian.

The "Ozarkian system," proposed by Ulrich and described on page 602, has not yet found wide acceptance and differences of opinion with regard to it are still so great that a satisfactory adjustment is more or less remote. Hence its inclusion as a new period in the table on p. 443 is premature. The discussion would be more intelligible to the general

reader if supplemented by a table giving sections at the places named.

On page 443 Waverlian and Tennessian are given as new periods and on page 732 their subdivisions are shown. The author apparently adopts the proposals of Ulrich (Bull. Geol. Soc. Am., Vol. 22) with regard to Carboniferous nomenclature, although these proposals have thus far not received wide acceptance among geologists. The Waverlian here indicated as the lower division of the Carboniferous is made to include the Chattanooga, a departure from general usage, of which the student receives no hint, the Chattanooga being regarded by most writers as Devonian and not Carboniferous.

The break between the proposed Waverlian and Tennessian is placed between the Keokuk and the Warsaw as suggested by Ulrich, but Weller (Ill. Geol. Survey, Mon. I.) points out that there is no satisfactory basis for differentiating the Warsaw from the subjacent Keokuk, the faunal relations between the two being very close, but that, on the other hand, a notable break does occur above the Warsaw. The disagreement between students of the Carboniferous in the Mississippi Valley as to important features of stratigraphy and the fact that none of the various breaks in the stratigraphic succession of the Mississippian has been demonstrated to have period value makes it inadvisable to introduce such names in the table, and especially to discuss them in the text as if they had recognized standing. Under such circumstances the headings, "Waverlian seas," "Land life of Waverlian time," "Tennessian seas," etc., are clearly misleading.

On page 732 the Pennsylvanian and Permian are grouped together "as if representing but a single period, for the reason that there is no break of marked importance in the sedimentation between these two periods in America." It seems like a backward step to give up the differentiation already gained.

An innovation in the table, pp. 442–445, is the inclusion of revolutions and intervals, for example Cascadian Revolution and Epi-Mesozoic Interval. The Laramide and Appalachian revolutions begin with the earliest Cretaceous (Upper Cretaceous) and Pennsylvanian respectively. This is apparently in accord with the definitions of revolutions and critical periods set forth on p. 453, but it may be questioned if the term revolution should be made so inclusive.

On page 442 of the table the Dakota (Dakotian? to agree with Coloradian) appears inadvertently omitted from the Cretaceous column.

A few additional comments on the body of the text follow:

Page 486. "The seas of the continental shelves . . . are the ones from which all other water bodies of the world have been colonized." This statement takes no cognizance of other views.

Page 598. Of 14 genera mentioned as characteristic of the Wau-

cobian 6 are not illustrated in the accompanying Plate I., and on pages 599 and 601 only 3 genera out of 25 listed as characteristic of Acadian and Croixian time, respectively, are illustrated in Plate 2. The genera represented in the 23 figures of the 2 plates are with a few exceptions not mentioned in the text. This is unfortunate for the student. Where paleontologic data are reduced to the minimum, special effort should be made to illustrate, so far as practicable, the genera mentioned. Similar criticism might be made of Plate 20, page 735, in which no brachiopods appear, notwithstanding their mention in the text and their importance during the Mississippian period.

Page 623. The reference to the controversy between Sedgwick and Murchison (see also p. 659) over the Cambrian and Silurian does scant justice to Murchison.

Page 777. The excellent chapter on coal, occupying 18 pages, would be improved by the addition of a brief discussion of heating values if the chapter were organized under economic deposits, as above suggested.

Appendix *B* gives the scientific names of the fossils illustrated in the text. In the opinion of the reviewer the interests of the student and general reader would have been better served had the names accompanied the illustrations.

Both parts of the volume have been brought up to date, so far as that is practicable in a textbook, and express the later views on many controversial topics.

A serious lack that will be noted by many is caused by the omission of footnote or other direct reference to original sources. Numerous authorities are cited in the text but with a few exceptions only by name and little assistance is given in collateral reading.

Unfortunately the book is marred by infelicitous style in many places. On page 303, for example, we read: "It is thus usually easy to tell what rocks an igneous mass is younger than, by examining its contacts with them, but much more difficult to say what ones it is older than, because usually the younger beds have been eroded away if the mass is exposed, or they still conceal it, or it may never have been covered."

There is no list of illustrations, but the latter as a whole are well selected, and well executed, and include halftones, drawings, and maps. A goodly number is credited to the United States Geological Survey, while other surveys and private sources have also been drawn upon. The halftones are excellent and expressive. A particularly pleasing feature is the inclusion of the portraits of many of the founders of geology. The fossil cuts are clear and the diagrams for the most part well drawn. In Fig. 50, p. 63, the stream that flows under the natural bridge has suffered a great decrease in volume from that which it had at the time of excavating the meandering valley, as shown by the decreased

radii of its curves. The diagram is misleading in that the reader may suppose the change due to the cut-off which produced the bridge, whereas it must have been due to other causes not shown in the diagram. There are 72 maps large and small in the text besides the colored geologic map at the end of the volume. The 54 maps of Part II. are largely paleogeographic and are all of great interest. The geologic map is not up to the standard of the other illustrations. With the same degree of generalization greater accuracy could have been secured. The color registration is poor and a different style of nomenclature is adopted in the legend from that used in the text.

The index is well arranged and fairly complete. Some omissions are doubtless unavoidable in a work of this character. For example, the terms *undertow* and *littoral*, or shore currents, though italicized on page 89 do not appear in the index.

The typography and press work maintain the usual high standards of the publishers.

Altogether the book is a distinct contribution to the textbook literature of geology. It is, however, less conservative than is desirable in the presentation of the subject to beginners.

G. R. MANSFIELD.

SCIENTIFIC NOTES AND NEWS[1]

PROFESSOR W. H. TWENHOFEL, of the University of Kansas, has been appointed associate professor of geology at the University of Wisconsin, to succeed Professor Eliot Blackwelder.

J. D. THOMPSON, JR., assistant in geology at Cornell University, has accepted a position as geologist with the Continental Oil Co. of Oklahoma.

THE TACOMA EXPLORATION CO., under W. R. Rust, has opened offices in Tacoma. They will take up the examination and development of mines and prospects.

W. F. HORTON, mining technologist of the bureau of mines, has resigned to accept a position with the Sterling Steel Co.

H. FOSTER BAIN, of the *Mining Journal,* has started for South Africa to study conditions on the Rand.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.